

# **Aviation Maintenance Human Factors Accident Analysis**

## **HFACS-ME**

**Human Factors Analysis and Classification  
System – Maintenance Extension**



Naval Safety Center  
School Of Aviation Safety



Student Guide v3.0

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# Introduction

Naval Aviation, in an effort to reduce human error in aviation maintenance, developed an analytical tool referred to as Maintenance Extension of the Human Factors Analysis and Classification System (HFACS-ME).

The HFACS-ME framework has proven effective in capturing the nature of latent conditions which “set the stage” for active failures in Naval Aviation maintenance. In cooperation with the FAA and NASA, HFACS-ME was adapted for civilian aviation applications.

This training guide and the accompanying presentations will introduce you to the HFACS-ME framework and its elements. Case studies, based upon NTSB commercial aviation accident investigations, are used during the workshop to provide individuals the necessary skills and confidence to apply HFACS-ME within their own organizations.

Appendix O of the Naval Aviation Safety Program, provided under Tab 1, offers additional background information on the HFACS-ME taxonomy. The document serves as an excellent reference source before and after completing this training program.

The Naval Safety Center and Naval Postgraduate School would like to acknowledge its sponsors in this endeavor:

Ms. Jean Watson  
FAA Flight Standards Service  
Washington, DC

Dr. Barbara Kanki  
NASA Ames Research Center  
Moffett Field, CA

## NAVAL SAFETY PROGRAM, APPENDIX 0 (HFACS-ME)

HFACS has been adapted to capture maintenance human factors. Termed the “Maintenance Extension” (HFACS-ME), it facilitates the recognition of absent or defective defenses at four levels, including, Unsafe: Management Conditions (Organizational & Supervisory), Maintainer Conditions, Working Conditions, and Maintainer Acts (see Figure 1). This framework can be used to identify targets for intervention. HFACS-ME clearly addresses Marx’s (1998) valid concern that human error has been “under-served” by traditional maintenance error analysis systems. Most systems adequately identify what happened, but not why it occurred.

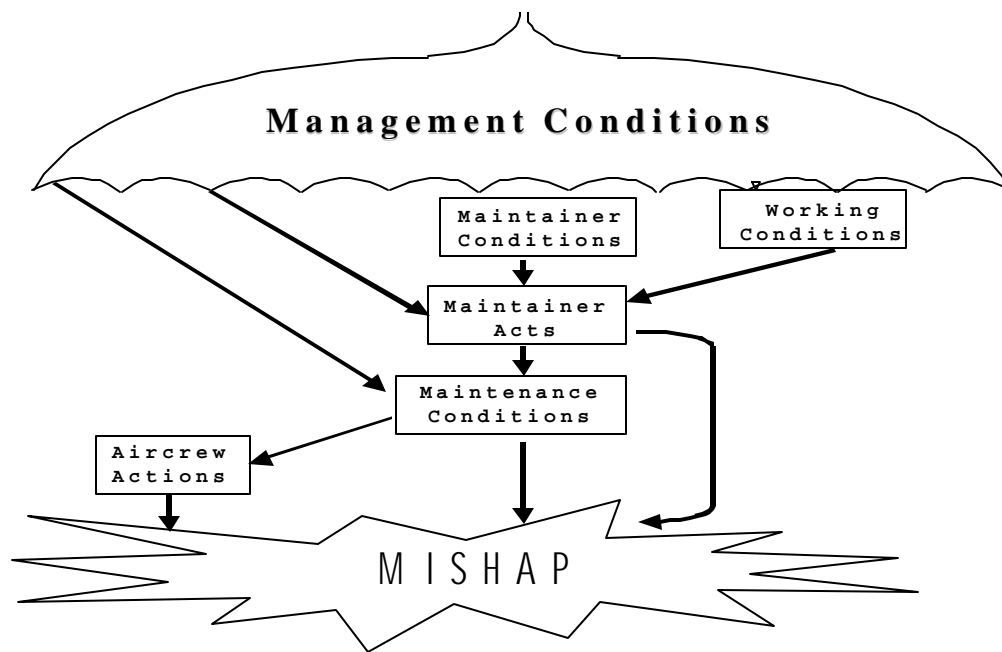


Figure 1. The HFACS - Maintenance Extension (HFACS-ME).

Unsafe Management, Maintainer, and Working Conditions are latent conditions that can impact a maintainer’s performance and lead to an Unsafe Maintainer Act, an active failure. An Unsafe Maintainer Act may directly cause a mishap or injury (e.g., a maintainer runs a forklift into the side of an aircraft and damages it). It could also cause an Unsafe Maintenance Condition, which the aircrew would have to deal with on take-off, in-flight, or on landing (e.g., an over-torqued hydraulics line that fails in flight causing a fire or an improperly rigged landing gear that collapses on touchdown). Finally, it is important to note that Unsafe Management Conditions related to design for maintainability, prescribed maintenance procedures, and/or standard maintenance operations can be inadequate and lead to Unsafe Maintenance Conditions. Each major component of HFACS-ME has three orders that reflect a shift from a macro to a micro perspective in establishing why a maintenance error occurred (see Table 1).

For the most part HFACS-ME is used much the same way for maintenance factors as HFACS is for aircrew factors. For example, a supervisor who fails to correct a maintainer who routinely bends the rules while performing maintenance would be considered an Unsafe Management Supervisory Condition, failure to correct a known problem. Similarly, a maintainer who has a marital problem and cannot focus on a maintenance operation has fallen prey to an Unsafe Maintainer Medical Condition (Adverse Mental State). Further, a maintainer who must work in a heavy rain could experience difficulty due to an Unsafe Working Environmental Condition (Unsafe Weather/Exposure). Ultimately these conditions could lead to Unsafe Maintenance Acts such as reversing a step in a procedure (Attention/Memory Error) as well as not using the prescribed manual (Routine Violation). The following paragraphs provide a brief illustration of the four major components of the HFACS-ME taxonomy. Tables are provided with examples of third order events mapped with Boeing's Maintenance Error Decision Aid –MEDA (Rankin, 2000). MEDA is an established industry tool that identifies what contributed to a maintenance incident. Pairing HFACS-ME with MEDA links what happened with why it happened.

Table 1. HFACS- ME Taxonomy		
First Order	Second Order	Third Order
Management Conditions	Organizational	Inadequate Processes Inadequate Documentation Inadequate Design Inadequate Resources
	Supervisory	Inadequate Supervision Inappropriate Operations Uncorrected Problem Supervisory Misconduct
Maintainer Conditions	Medical	Adverse Mental State Adverse Physical State Unsafe Limitation
	Crew Coordination	Inadequate Communication Inadequate Assertiveness Inadequate Adaptability/Flexibility
	Readiness	Inadequate Training/Preparation Inadequate Certification/Qualification Personnel Readiness Infringement
Working Conditions	Environment	Inadequate Lighting/Light Unsafe Weather/Exposure Unsafe Environmental Hazards
	Equipment	Damaged/Unserviced Unavailable/Inappropriate Dated/Uncertified
	Workspace	Confining Obstructed Inaccessible
Maintainer Acts	Error	Attention/Memory Knowledge/Rule Skill/Technique Judgment/Decision
	Violation	Routine Infraction Exceptional

## Unsafe Management Conditions

Management Conditions that contribute to active failures consists of both Organizational and Supervisory factors (see Table 2). Examples of Organizational Management Conditions are: a manual omits a step calling for an o-ring to be installed (Inadequate Processes); a technical publication does not specify torque requirements (Inadequate Documentation); a poor component layout prohibits direct viewing during inspection (Inadequate Design); and a shortage of tools leads to using what is immediately available (Inadequate Resources). Examples of Supervisory Management Conditions include: a commander does not ensure that personnel wear required protective gear (Inadequate Supervision); an engine change is performed despite a high sea state without considering the risks (Inappropriate Operations); a supervisor does not correct cutting corners in a procedure (Uncorrected Problem); and a supervisor orders personnel to wash an aircraft without training (Supervisory Misconduct).

Table 2. Select List of Unsafe Management Conditions	
ORGANIZATIONAL	SUPERVISORY
<u>Inadequate Processes</u> Task Complex/Confusing Procedures Incomplete Non-Existing Procedures	<u>Inadequate Supervision</u> Task Planning/Organization Task Delegation/Assignment Amount of Supervision
<u>Inadequate Documentation</u> Not Understandable Information Unavailable Conflicting Information	<u>Inappropriate Operations</u> Information Not Used Unrealistic Expectations Improper Task Prioritization
<u>Inadequate Design</u> Poor Layout/Configuration Poor/No Accessibility Easy to Incorrectly Install	<u>Uncorrected Problem</u> Manual Not Updated Parts/Tool Incorrectly Labeled Known Hazards Not Controlled
<u>Inadequate Resources</u> Parts Unavailable Manning Shortfall Funding Constraint	<u>Supervisory Misconduct</u> Policy/Procedures Not Followed Policy/Procedures Not Enforced Assigned Unqualified Maintainer

## Unsafe Maintainer Conditions

Maintainer Conditions that lead to active failures consists of Medical, Crew Coordination, and Readiness factors (see Table 3). Examples of Maintainer Medical Conditions are: a maintainer with life stress has impaired concentration (Adverse Mental State); a maintainer is fatigued from working 20 hours straight (Adverse Physical State); and a short maintainer cannot visually inspect an aircraft component (Unsafe Limitation).

Examples of Maintainer Crew Coordination conditions include: a maintainer using improper hand signals (Inadequate Communication); a maintainer signs off an inspection due to perceived pressure (Inadequate Assertiveness); a maintainer downplays a discrepancy to meet the flight schedule (Inadequate Adaptability/ Flexibility). Examples of Maintainer Readiness Conditions encompass: a maintainer working on an aircraft skipped a requisite training evolution (Inadequate Training/Preparation); a maintainer engages in a procedure they have not been qualified to perform (Inadequate Certification/ Qualification), and a maintainer is intoxicated on the job (Personnel Readiness Infringement).

Table 3. Select List of Unsafe Maintainer Conditions

MEDICAL	CREW COORDINATION	READINESS
<u>Adverse Mental State</u> Peer Pressure Complacency Life Stress	<u>Inadequate Communication</u> Non Standard Hand Signals Inappropriate Log Entry Inadequate Shift Passdown	<u>Inadequate Training/Preparation</u> New/Changed Task Inadequate Skills Inadequate Knowledge
<u>Adverse Physical State</u> Health/Illness Fatigue Circadian Rhythm	<u>Inadequate Assertiveness</u> Peer Pressure Rank Gradient New to Group	<u>Inadequate Certification/Qualification</u> Not Certified for Task Incomplete PQS Not Licensed to Operate
<u>Unsafe Limitation</u> Body Size/Strength Eye Sight/Hearing Reach/View	<u>Inadequate Adaptability/Flexibility</u> Non-adherence to Change Different from Similar Tasks Disregard of Constraint	<u>Personnel Readiness Infringement</u> Self-Medication Alcohol Use Crew Rest

### Unsafe Working Conditions

Working Conditions that can precipitate active failures consists of Environment, Equipment, and Workspace factors (see Table 4). Examples of Environment Working Conditions are: a maintainer working at night without artificial lighting (Inadequate Lighting/Light); a maintainer securing an aircraft in a driving rain improperly chocks a wheel (Unsafe Weather/Exposure); and a maintainer slips on a pitching deck (Unsafe Environmental Hazard). Examples of Equipment Working Conditions include: a maintainer uses a faulty test set (Damaged/Unserviced); a maintainer does not use a jack because all are in use (Unavailable/Inappropriate); a maintainer uses an out of date manual (Dated/Uncertified). Examples of Workspace Working Conditions encompass: a maintainer in a fuel cell cannot reach a component (Confining); a maintainer's view in spotting an aircraft is obscured by catapult steam (Obstructed); and a maintainer is unable to perform a corrosion inspection that is beyond his reach (Inaccessible).

Table 4. Select Examples of Unsafe Working Conditions		
ENVIRONMENT	EQUIPMENT	WORKSPACE
<u>Inadequate Lighting/Light</u> Inadequate Natural Light Inadequate Artificial Lighting Dusk/Nighttime	<u>Damaged/Unserviced</u> Unsafe/Hazardous Unreliable/Faulty Inoperable/Uncontrollable	<u>Confining</u> Constrained Tool Use Constrained Equipment Use Constrained Position
<u>Unsafe Weather/Exposure</u> Temperature Precipitation Wind	<u>Unavailable/Inappropriate</u> Unavailable for Use Inappropriate for Task Power Sources Inadequate	<u>Obstructed</u> Not Visible Not Directly Visible Partially Visible
<u>Unsafe Environmental Hazards</u> High Noise Levels Housekeeping/Cleanliness Hazardous/Toxic Substances	<u>Dated/Uncertified</u> Unreliable/Faulty Inoperable/Uncontrollable Miscalibrated	<u>Inaccessible</u> Totally Inaccessible Not Directly Accessible Partially Accessible

#### Unsafe Maintainer Acts

Maintainer Acts are active failures which directly or indirectly cause mishaps, or lead to a Latent Maintenance Condition that an aircrew would have to respond to during a given phase of flight. Unsafe Maintainer Acts include errors and violations (see Table 5). Examples of errors in Maintainer Acts include: a maintainer misses a hand signal (Attention/Memory); a maintainer inflates a tire using a pressure required by a different aircraft (Knowledge/Rule); a maintainer roughly handles a delicate engine valve causing damage (Skill/Technique); and a maintainer misjudges the distance between a tow tractor and an aircraft wing (Judgment/Decision-Making). Examples of Violations in Maintainer Acts include: a maintainer engages in practices, condoned by management, that bend the rules (Routine); a maintainer elects to stray from accepted procedures to save time, bending a rule (Infraction); a maintainer due to perceived pressure omits an inspection and signs off an aircraft (Exceptional); and a maintainer willfully breaks standing rules disregarding the consequences (Flagrant).

Table 5. Select List of Unsafe Maintainer Acts	
ERROR	VIOLATION
<u>Attention/Memory</u> Omitted Procedural Step Distraction/Interruption Failed to Recognize Condition	<u>Routine(if norm)</u> Inappropriate Tools/Equipment Procedures Skipped/Reordered Did Not Use Publication
<u>Knowledge/Rule Based</u> Inadequate Task Knowledge Inadequate Process Knowledge Inadequate Aircraft Knowledge	<u>Infraction (if isolated)</u> Inappropriate Tools/Equipment Procedures Skipped/Reordered Did Not Use Publication
<u>Skill/Technique Based</u> Poor Technique Inadequate Skills Inappropriate Technique	<u>Exceptional (if minor)</u> Gundecking Qualifications Not Using Required Equipment Signed-off Without Inspection
<u>Judgment/Decision-Making</u> Exceeded Ability Misjudged/Misperceived Misdiagnosed Situation	<u>Flagrant(if blatant)</u> Gundecking Qualifications Not Using Required Equipment Signed-off Without Inspection

#### References

- Marx, D. (1998). Learning from our mistakes: A review of maintenance-error investigation and analysis systems. Washington, DC: FAA
- Rankin, W. (2000). Maintenance Error Decision Aid. Seattle, WA: Boeing Aircraft Corp.


# Introduction to Maintenance Error Analysis

**Objective:** This presentation introduces the student to human error in aviation maintenance and the subsequent development of theories that help us to understand those errors. Building upon these theories, the Human Factors Analysis and Classification System – Maintenance Extension (HFACS-ME) framework was developed for use within accident investigations and trend analysis to capture the key elements of aviation maintenance errors.

Slide 1



Introduction  
to  
Maintenance Error  
Analysis



Naval Safety Center  
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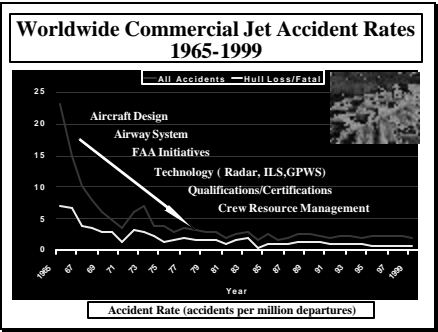
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Slide 2



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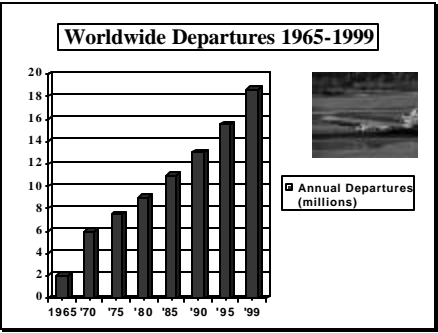
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Slide 3



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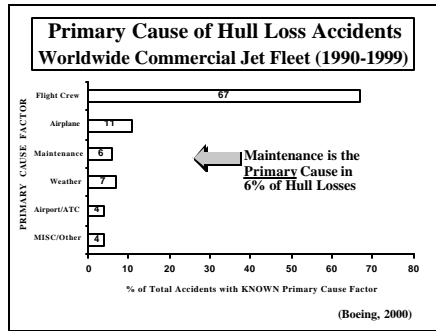
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Slide 4



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Slide 5

**How Significant are Maintenance Factors?**



Studies found that:

- Maintenance contributed to 15% of commercial jet accidents (Boeing, 1995)
- Maintenance was the 2nd greatest contributor to fatalities, following CFIT (CAA, 1992)

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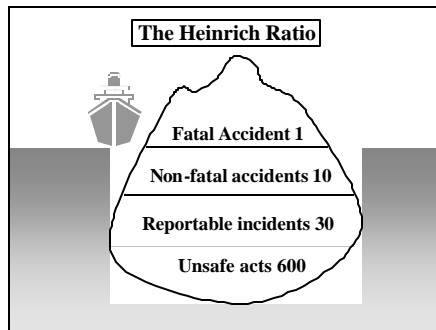
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Slide 6



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## Slide 7

### Additional Maintenance/Ramp Error Data

20-30% of engine in-flight shutdowns and 50% of engine-related flight delays/cancellations are caused by maintenance error (Boeing, 1997)

48,800 non-airworthy aircraft are dispatched per year as a result of maintenance error (Marx, 1998)

Ramp accidents cost \$2-2.5 Billion annually (Ramp Safety, Vol. 11:3)

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## Slide 8

### Maintenance Accident Costs

- Avg. cost of an inflight engine shutdown is \$500,000
- Avg. cost of a flight cancellation is \$50,000
- Avg. cost of a return to gate is \$15,000
- Avg. ground damage incident costs \$70,000
- One airline estimates \$75-\$100 million/year is lost
- Airline Transport Association estimates that ground damage costs \$850 million/yr

(Source: bbskyway.faa.gov)

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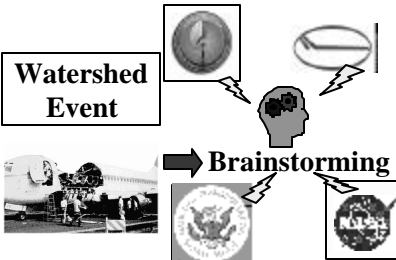
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## Slide 9

### Paradigm Shift: Aloha Airlines, 1988

**Watershed Event**





**Brainstorming**

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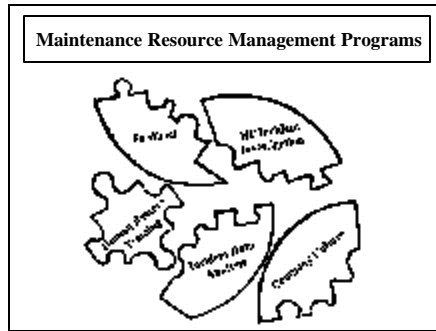
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Slide 10



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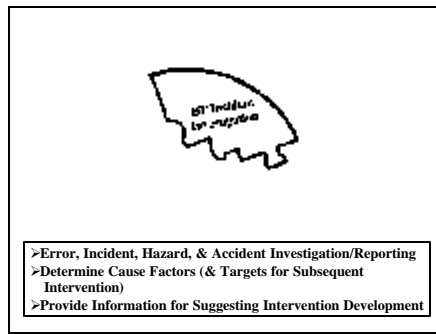
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Slide 11



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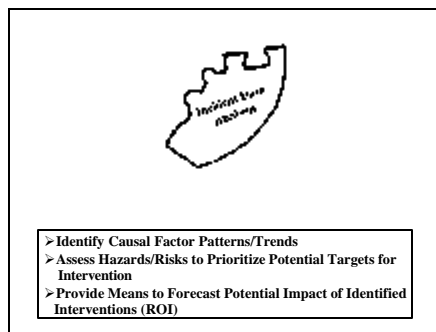
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Slide 12



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Slide 13



Interlock

- Establish Metrics for Evaluating Intervention Effectiveness (ROI)
- Provide Lessons Learned for Specific Operations/ Locations
- Permit Team/Individual Participation in the Development of Interventions

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Slide 14



Eye Icon Culture

- Reporting Errors, Incidents, Hazards, & Accidents
- Active Participation in Intervention Development
- Proactive Identification of Hazards/Errors
- Top Management Support & Individual Buy-In

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Slide 15



Puzzle Piece

- **Individual Worker**- Awareness & Skill Development (Performance Optimization, Personal Safety, Team Synergy, & Proactive Improvement)
- **Line Supervisor**- Awareness, Skill (listed above), Implementation, & Investigation/Reporting
- **Upper Management**- Awareness, Overview of Skills, Investigation/Reporting, & Implementation, & Metrics
- **Safety/OA**- Awareness, Skill Development (listed above), Implementation, Investigation/Reporting, & Metrics

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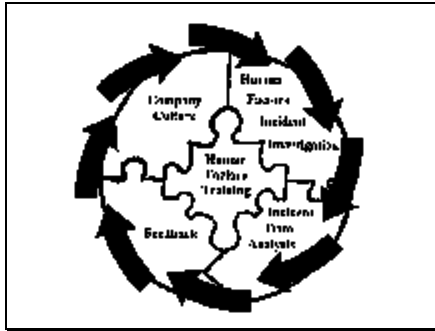
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Slide 16



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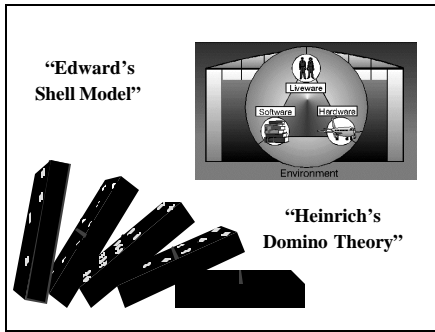
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Slide 17



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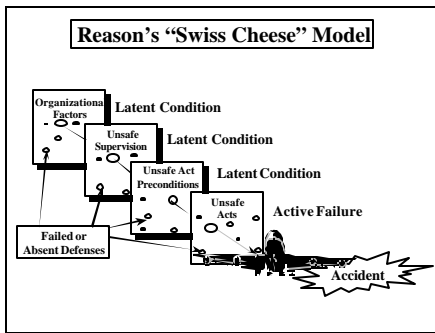
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Slide 18



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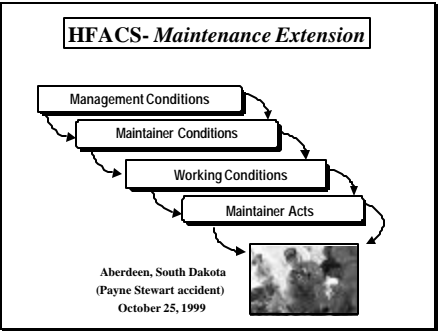
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Slide 19



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Slide 20

**HFACS-ME in Commercial Aviation**

The FAA's Office of Aviation Medicine requested that the US Navy's School of Aviation Safety apply HFACS-ME to commercial airline accidents

15 NTSB Maintenance related accident reports were analyzed from provided sets

HFACS-ME was successfully used to code existing NTSB reports

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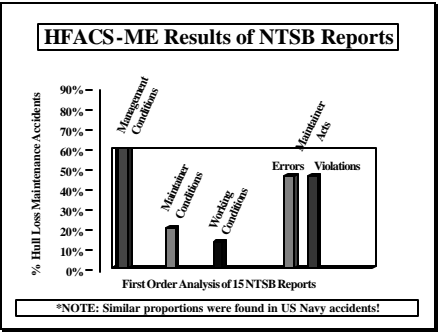
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Slide 21



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Slide 22

**HFACS-ME Summary**

(1) HFACSME is effective in classifying maintenance errors.

(2) HFACSME may be utilized on both major and minor accidents to fully capture maintenance errors.

(3) HFACSME enables organizations to develop successful intervention strategies.

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Slide 23

**Ramp & Maintenance  
Incentive for Safety Improvement**



**Questions?**

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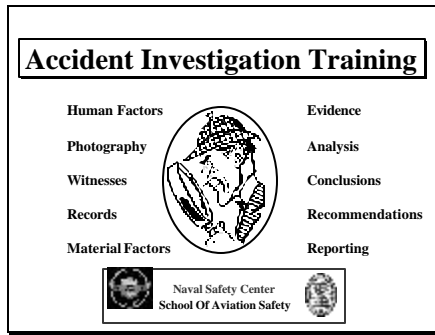
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## **PRESENTATION TWO**

# **Accident Investigation Training**

**Objective:** This presentation introduces the student to the accident investigation process. The examples provided are designed to quickly familiarize the student with the basic practices used by aviation accident investigators and provide the necessary motivation to thoroughly investigate all levels of accidents and incidents.

Slide 1



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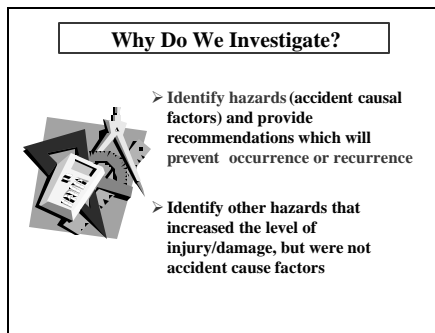
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Slide 2



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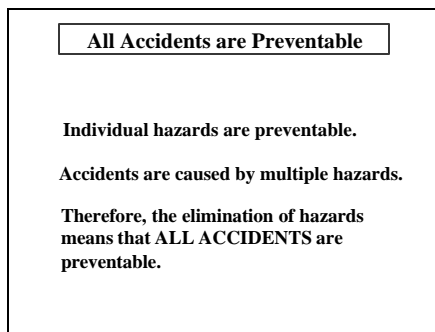
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Slide 3



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## Slide 4

**Purpose of YOUR Investigation?**

- **Punishment of personnel and lawsuit protection?**  
“Legal” approach
- **Simply describe WHAT happened?**  
Historical use only because corrective actions need to address WHY something happened
- **Prevent another accident or incident?**  
“Safety” approach (and “Legal”, if done correctly)

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## Slide 5

**Effort vs Severity**

**Hazard Reports, Incident Reports, and Accident Reports....**  
**ARE THERE MAJOR DIFFERENCES?**

- Evidence
- Analysis
- Conclusions
- Recommendations

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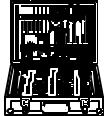
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## Slide 6

**Investigation Requirements**

<p>Accident/Incident Plan</p> 	<p>Investigator In Charge</p> 
<p>Investigation Kit</p> 	<ul style="list-style-type: none"><li>➤ Teams?</li><li>➤ Individuals?</li><li>➤ External/Internal to organization?</li><li>➤ Safety, Maintenance, or others?</li></ul>

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## Slide 7

**Investigation Phases**

- **Accident Response and Evidence Gathering**
- **Critical Examination**
- **Preliminary Analysis**
- **Validation of Findings**

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## Slide 8

**Initial Actions**

- **Activate Plan**
- **Control the Site**
  - Security, Access, and Hazards
- **Notification of Personnel**
- **Get the BIG Picture**



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## Slide 9

**Accident Response and Evidence Gathering**

- **Environment**
- **Components/Parts**
  - Is anything missing?
- **Site Photographs**
  - Controls and Switches
- **Rough Sketch/Diagram**

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Slide 10

**Accident Response and Evidence Gathering**

- **Tag All Identifiable Parts**
  - Illustrated Parts Breakdown
  - Maintenance Personnel
- **Write Down Questions for Later Research**
- **Secure Records**
- **ID Witnesses**

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Slide 11

**Tools to Obtain Evidence at the Site**

- **Photography**
- **Diagrams**
- **Witness Interviews**

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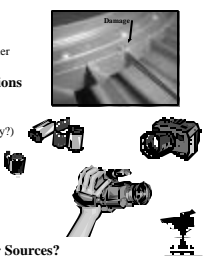
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Slide 12

**Photography Considerations**

- **Experience**
  - Professional photographer
  - Investigation team photographer
- **Restrictions and Limitations**
  - B&W vs Color Film
  - Commercial Developing
  - Photo Control (Safety Use Only?)
- **Cameras**
  - 35mm SLR with Zoom
  - Instant
  - Digital?
  - Video
- **Security Cameras/ Other Sources?**



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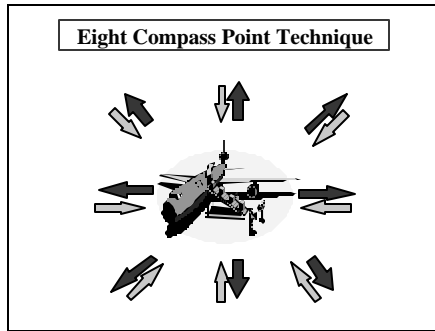
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Slide 13



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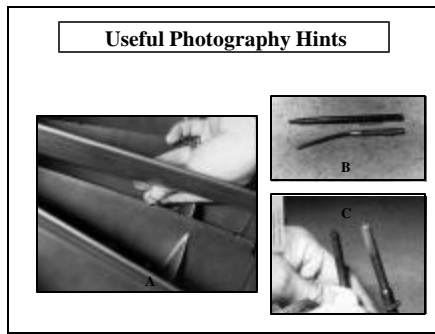
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Slide 14



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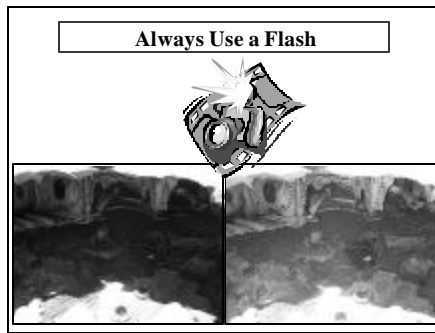
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Slide 15



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## Slide 16

**Wreckage Diagrams**

➤ **Working Tool**

➤ **Why Do One?**

- Do You Have All The Parts?
- Controlled/Uncontrolled Damage?
- Document environment scars

➤ **Types of Diagrams**


A- Rough

B- Polar


C- Linear

D- Grid


- Other?



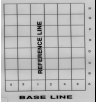
A



B



C



D

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## Slide 17


**Witness Interviews**

**RULES TO LIVE BY:**

➤ **One on One Interviews**

➤ **Never Interrupt**

➤ **Pencil & Paper – AVOID!**



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## Slide 18

**Interview Process**


➤ **Set up the Interview**

- Atmosphere
- Non-threatening

➤ **State the Policy on Use of Safety Report Information**

➤ **Tape Record the Interview**

**Start at a Point Prior to the Accident Event**



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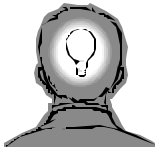
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Slide 19

**Memory Enhancing**

- **Recreate the Scene**
- **Focused Retrieval**
  - Help Witness Concentrate
  - Encourage Witness to Talk
  - Bring Up Related Issues
- **Extensive Retrieval**
- **Don't Correct/Interrupt**
- **Language**
  - Customs
  - Don't Talk Down



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Slide 20

**Talk, Talk, Listen, Talk**

- **Talk**
  - Witness Narrates Entire Sequence Uninterrupted
- **Talk**
  - Have Witness Repeat Entire Sequence Again
- **Listen**
  - Listen to Both Sequences
- **Talk**
  - Do You Remember Any Other Details?

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Slide 21

**Records**

- Operations**
- Maintenance**
- Safety**
- Administrative**
- Weather Reports**



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Slide 22

**Operational Records**



- **Work Schedule**
  - Working Copy
  - Authorized Task
  - Test Mission
  - Schedule Control
  - Logic of Assignment
- **Planning**
  - Pre-Task Planning & Brief
  - Actual operation
  - Records, Witnesses, Videos
- **Personnel**
  - Adequate Training
  - Qualifications
  - Currency vs Proficiency



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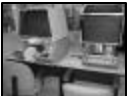
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Slide 23

**Maintenance Records**

- **Phase Inspections**
- **Changes and Modifications**
- **Inspections**
- **Gripes/Discrepancies**
  - Outstanding & Repeat
- **Tool Control**



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Slide 24

**Safety and Administrative**

- **Safety**
  - Previous accident reports (similarities, clues)
  - Databases (trends)
  - Prior interventions (successful?)
- **Administrative**
  - Organizational Planning Documents
  - Personnel Issues (awards/reprimands)/Pay
  - Work history
  - Training
- **Weather Reports**



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Slide 25

**Expert Help?**

- **Manufacturers**
- **FAA/NTSB**
- **Unions**
- **Aviation/Trade Organizations**
- **OSHA/EPA**
- **Consultants/Contractors**

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Slide 26

**Organizing Evidence**

- **Acquire ALL Evidence First**  
(wreckage, interviews, records, etc.)
- **Separate/Categorize Evidence for Ease of Management**  
(folders, hangar layouts, documents, data forms, etc.)
- **Methodically Examine and Compare Evidence**  
(specific team duties, meeting times)



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Slide 27

**Critical Examination**

- **Engines/Machinery**
  - Were they operable?
  - Performance?
- **Equipment/Structures**
  - Damage caused by failure or impact
  - Do you have all of the parts?
- **Fire**
  - Pre or Post Accident
  - Explosion?



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Slide 28

Critical Examination

➤ Controls

- Continuity of Controls

- Cotter Keys, Safety Wire

- Shear Wire/Pins

➤ Survivability/Egress

- Method of Egress Used

- Document Success as Well as Failure

➤ Unusual Damage?

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Slide 29

Examples of Critical Examinations

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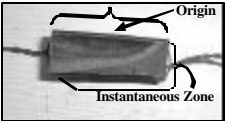


B

Fatigue Zone

Origin

Instantaneous Zone



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Slide 30

Critical Examination: TWA 800

Fluid	Flash Point (°F)	Autoignition Temperature (°F)
Air/Gas	-45	830
(Any grade)		
JP-4, Jet B	-40	430
JP-4	140	400
JP-5	140	400
JP-6, Jet A, Jet A-1	130	400
JP-8	110	400
Lubricating Oil	430	730
(MIL-L-7808)		
Hydraulic Fluids		
MIL-H-5606B	105	435
MIL-H-43382	400	625
Skydrol 500 B4	320	945
Hydramine	126	310

NOTE: Temperatures are approximate and depend on test method and conditions.

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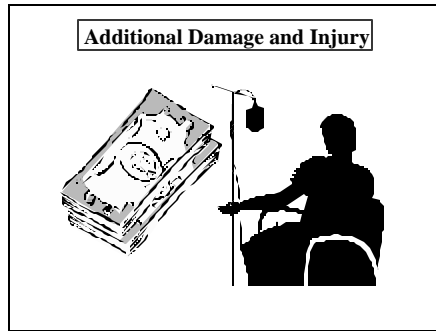
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Slide 31



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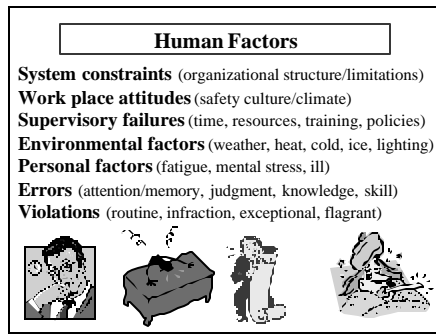
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Slide 32



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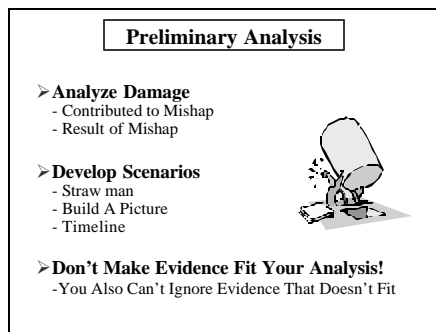
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Slide 33



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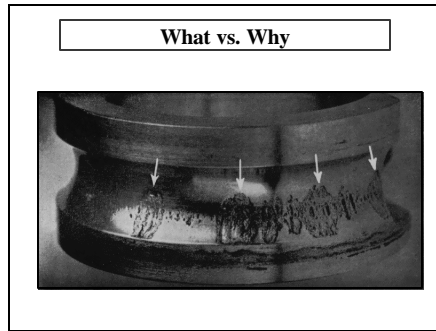
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Slide 34



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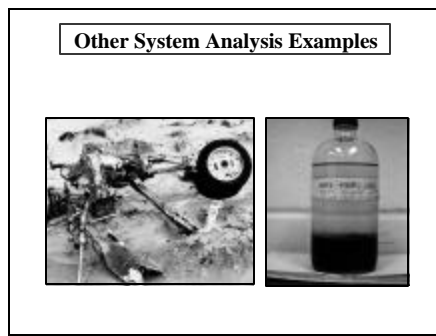
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Slide 35



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Slide 36

Validation of Findings

➤ **Has it Happened Before?**

- NTSB/FAA/Organization Data Bases
- Technical Representatives
- Corporate Knowledge

➤ **Research All Possible System Failures**



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Slide 37

**Conclusions**

**ONLY Your Accepted Cause Factors of This Accident!**

(Other hazards, agendas, etc. go elsewhere.)



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Slide 38

**Recommendations**

**IMPORTANT!**

- **Recommendations Must Directly Address EACH Cause Factor**
- **Attempt Three Recommendations per Cause Factor** (short/medium/long term fixes)
- **Avoid Generalizations** (review, study, etc.)

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Slide 39

**Reporting**

**Reports Must Be:**

- **Thorough** (include accepted and rejected factors)
- **Easy to read/access information**
- **Created and stored in a “standard” format**
- **Timely** (20-30 days is more than long enough)



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Slide 40

**Trend Analysis**



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Slide 41

**Equipment Wreckage**

➤ **Preservation**  
- First 24 Hours

➤ **Control of Wreckage**  
- Investigator in Charge or Maintenance?

➤ **Release of Wreckage**  
- Request Disposition Instructions  
- Chain of Custody



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Slide 42

**Environmental Concerns**

➤ **OSHA/EPA/HAZMAT Teams**  
- Advance Liaison  
- Develop a Game Plan

➤ **Accident Plan?**

➤ **Environmental Impact Statement**  
- EPA Walk Through  
- Crash Site Clean-Up  
- Organizational Responsibilities



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Slide 43

**Summary**

- No Pre-Conceived Notions...Let the Evidence Explain the Accident
- There is No Single Cause of an Accident
- No Two Accidents are Exactly Alike, but They Often Share Similar Hazards
- Do not Rely on Any Single Sources of Evidence
- VERIFY Your Findings and Conclusions
- Accident Reports Should Focus Only on Accident Causes...Not Other Hazards or Issues

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Slide 44

**Summary (continued)**

- Recommendations Must Resolve the Accident Cause Factors to Prevent Future Accidents
- Recommendations on Non-Factor Issues Will Only Detract From the Accident Report
- Short, Medium, and Long-Term Solutions Offer the Greatest Strategy for Accident Prevention
- No One Wants an Accident, so Punitive Actions Will Probably Not Prevent Future Accidents
- Punitive Actions WILL Limit the Cooperation and Effectiveness of Future Investigations

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Slide 45

**Questions?**



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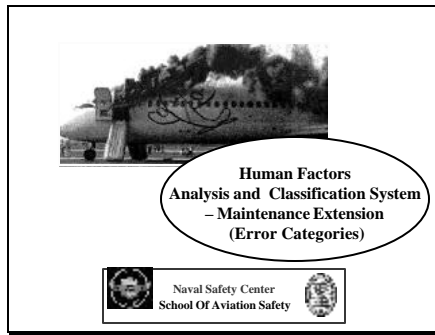
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## **PRESENTATION THREE**

# **Human Factors Analysis and Classification System- Maintenance Extension (Error Categories)**

**Objective:** This presentation introduces the student to the individual elements of the Human Factors Analysis and Classification System – Maintenance Extension (HFACS-ME) framework. The examples provided are designed to quickly familiarize the student with the framework and ensure the standardization of its use.

Slide 1



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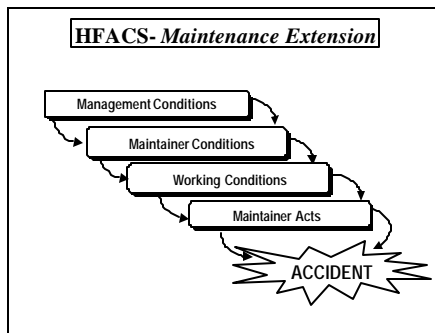
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Slide 2



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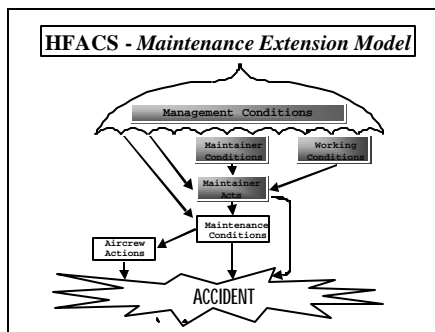
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Slide 3



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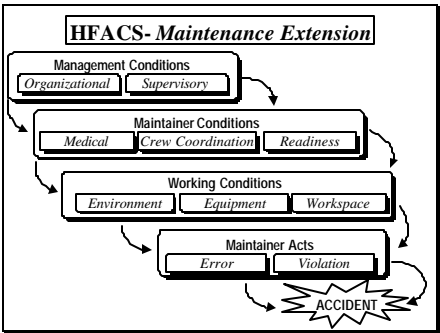
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Slide 4



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Slide 5

HFACS-ME Framework				
Error Categories of HFACS Framework				
First Order	Second Order	Third Order		
Management Conditions	Organizational	- Inadequate Processes - Inadequate Resources	- Inadequate Documentation - Inadequate Design	
	Supervisory	- Inadequate Supervision - Supervisory Misconduct	- Inappropriate Operations - Uncorrected Problem	
Maintainer Conditions	Medical	- Mental State	- Physical State	- Limitation
	Crew Coordination	- Communication	- Awareness	- Adaptability/Flexibility
	Readiness	- Training/Preparation	- Certification/Qualification	- Impairment
Working Conditions	Environment	- Lighting/Light	- Weather/Exposure	- Environmental Hazards
	Equipment	- Damaged/Unserviced	- Unavailable/Inappropriate	- Dated/Uncertified
	Workspace	- Cluttering	- Obstructed	- Inaccessible
Maintainer Acts	Error	- Attention/Memory Skill/Technique	- Judgment/Decision-Making	- Knowledge/Rule Based
	Violation	- Routine - Flagrant	- Infraction	- Exceptional

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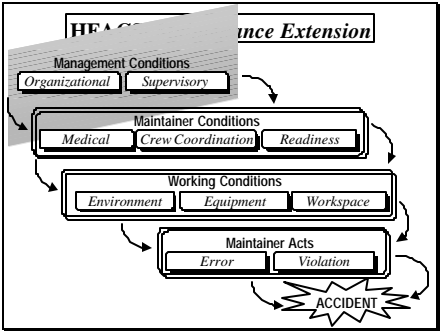
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Slide 6



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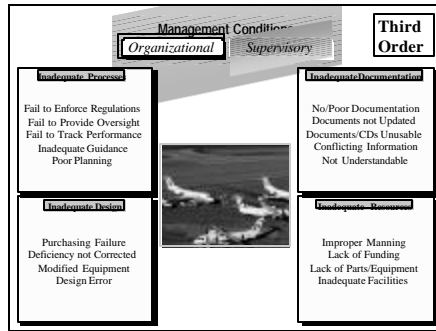
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## Slide 7




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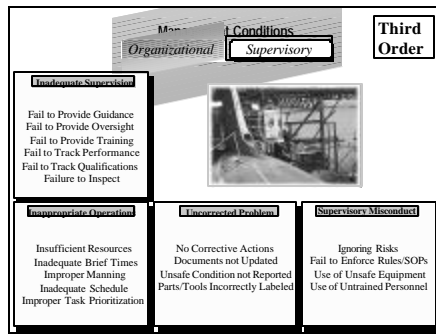
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## Slide 8




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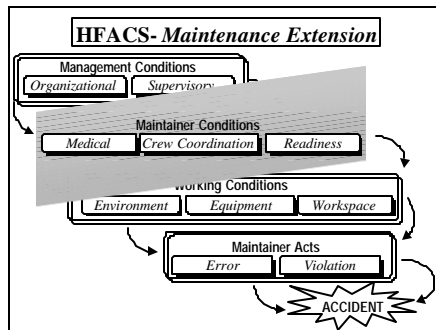
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## Slide 9




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Slide 10

Maintainer Conditions

MedicalCrew CoordinationReadiness

Third Order

<b>Mental State</b> Complacency Distraction Mental Fatigue Life Stress Misplaced Motivation Task Saturation Channelized Attention	<b>Physical State</b> General Health Medical Illness Physical Fatigue Circadian Rhythm	<b>Limitation</b> Hearing Limitation Visual Limitation Insufficient Reaction Time Incompatible Aptitude Physical Capability/Strength Physical Reach/Size
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Slide 11

Maintainer Conditions

MedicalCrew CoordinationReadiness

Third Orders

<b>Communication</b> Terms not Standardized Hand Signals not Standardized Documentation/Log Failures Documentation Delays Equipment Failures (radio) Equipment Use (lights/whistle) Inadequate Brief/Passdown	<b>Assessiveness</b> New to Group Fail to Brief/Make Suggestions Fail to Correct Discrepancies Fail to Confirm Messages Inattention to Feedback Waiver when Confronted Peer Pressure	<b>Adaptability/Resilience</b> Emergency Response System Failure Response Changes to Routine Different From Similar Task Team Member Changes
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Slide 12

Maintainer Conditions

MedicalCrew CoordinationReadiness

Third Order

<b>Training/Preparation</b> Not Trained for Task Inadequate Knowledge Unrealistic Training Ineffective OJT Inadequate Skills	<b>Intoxication</b> Intoxicated at Work Hang Over Inadequate Rest Drug/Medication Use
<b>Certification/Qualification</b> Not Certified in Task Not Certified in Model Qualifications Expired Not Licensed to Operate	

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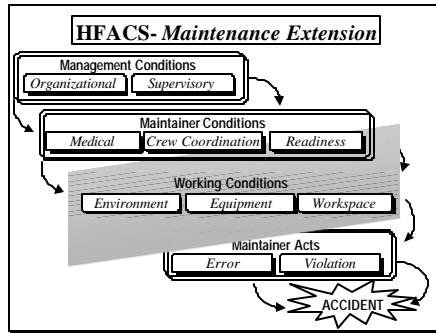
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# Slide 13




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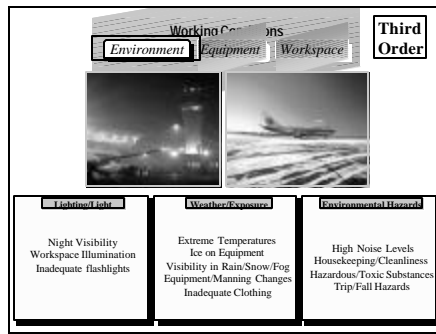
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# Slide 14




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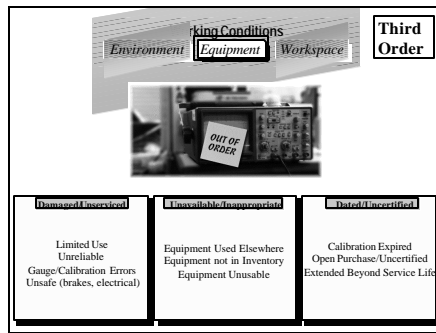
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# Slide 15




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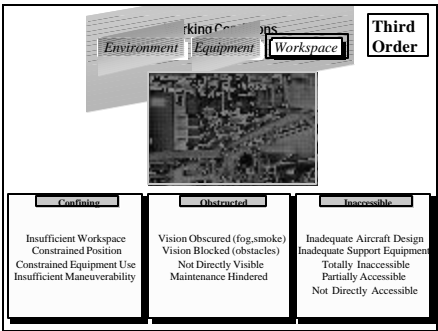
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Slide 16



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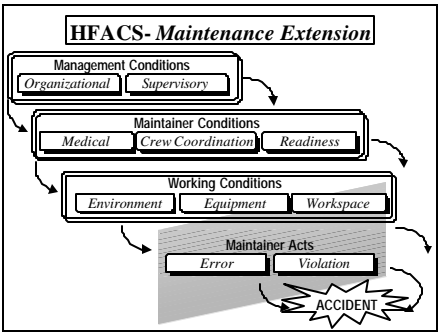
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Slide 17



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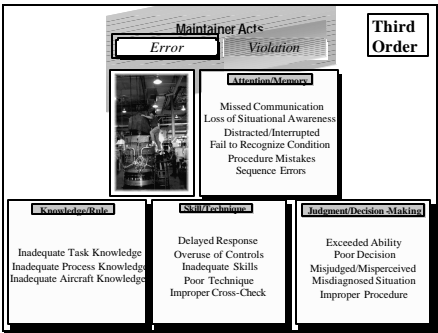
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Slide 18



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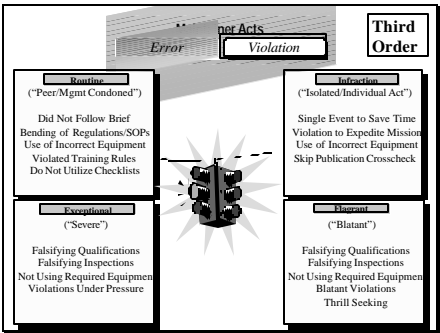
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Slide 19



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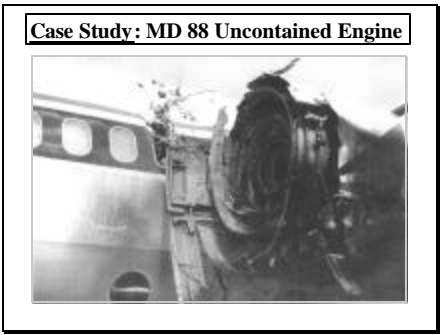
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Slide 20



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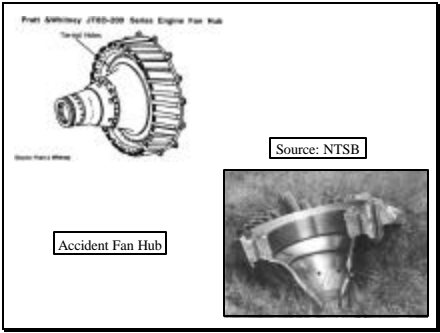
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Slide 21



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Slide 22

HFACS-ME Framework				
Error Categories of HFACS Framework				
First Order	Second Order	Third Order		
Management Conditions	Organizational	- Inadequate Processes	- Inadequate Documentation	- Inadequate Design
		- Inadequate Resources		
	Supervisory	- Inadequate Supervision	- Inappropriate Operations	- Uncorrected Problem
Maintenance Conditions		- Supervisory Misconduct		
	Medical	- Mental State	- Physical State	- Limitation
	Crew Coordination	- Communication	- Awareness	- Adaptability/Flexibility
Working Conditions	Readiness	- Training/Preparation	- Certification/Qualification	- Infringement
	Environment	- Lighting/Light	- Weather/Exposure	- Environmental Hazards
	Equipment	- Damaged/Unserviceable	- Unavailable/Inappropriate	- Dated/UnCertified
Maintainer Acts	Workpace	- Confusing	- Obstructed	- Inaccessible
	Error	- Attention/Memory	- Judgment/Decision-Making	- Knowledge/Rule Based
		- Skill/Technique		
	Violation	- Routine	- Infraction	- Exceptional
		- Flagrant		

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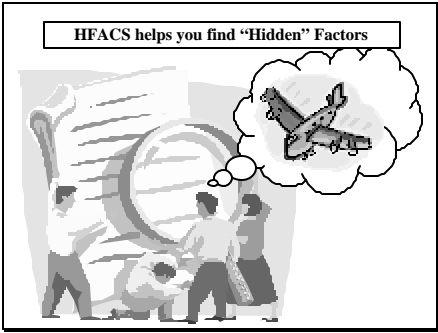
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Slide 23



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Slide 24

HFACS-ME Summary

**HFACS:**

- Identifies “why” cause factors occurred and their origins
- Identifies individual, as well as, system errors
- Promotes the discovery and implementation of effective intervention strategies
- Provides a framework for trend analysis
- Is useful for Accidents, Incidents, and Hazards

A detailed illustration of an aircraft carrier sailing on the ocean. The ship is shown from a side-on perspective, with its flight deck and various structures visible. The ocean is depicted with stylized waves.

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Slide 25



*Questions?*

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# HFACS-ME (Error Categories)

## Case Study

### MD-88 Uncontained Engine Failure on Takeoff

The MD-88's No.1 engine (a Pratt & Whitney JT8D-219 turbofan) failed during the initial part of its takeoff roll at a speed of approximately 40 knots. The captain took the controls from the first officer, placed the engine levers in idle, and stopped the aircraft on the runway. Uncontained debris from the front compressor fan hub penetrated the left aft fuselage, killing two passengers and seriously injuring two others. The debris also destroyed the radio and interphone wiring which eliminated standard communication between the cockpit and cabin. Approximately 25 passengers had exited the plane under direction of the flight attendants, but without the captain's approval and prior to engine shutdown. The captain ordered the remaining passengers to stay on the aircraft until suitable stairs arrived twenty-five minutes later.

During preflight, the first officer noted a small amount of oil on the engine's bullet nose and two missing rivets on the outboard section of the left wing. The captain and first officer discussed the discrepancies and concluded that the amount of oil was insignificant and that the airplane was airworthy. They departed without notifying maintenance. The missing rivets were logged in the airplane's logbook. The NTSB determined that the rivets and oil leak were not causal to the accident. The decision to not inform maintenance was later supported by Delta management, although it appears contrary to Delta's policy which requires flightcrews to notify maintenance of irregularities, or fluid leaks, at the gate. The NTSB concluded that Delta's written guidance lacks clarity on what constitutes maintenance "discrepancies" and "irregularities" and when to contact maintenance.

The NTSB concludes that no aircrew actions would have affected the outcome of the engine failure.

#### Background Maintenance Information:

The engine had a total time of 7,371.7 hours and 5,905 operating cycles since new. Delta was the original operator of the engine. It was installed on this aircraft six months prior to the accident. It had been removed from a different aircraft a month prior due to an oil leak in the compressor section. A carbon seal was replaced to repair that leak.

The engine's fan hub had a total time of 16,542 hours and 13,835 cycles at the time of the accident. The service life is limited to 20,000 cycles. The titanium hub was forged by Ladish Company in Wisconsin, and machined, finished, and inspected for Pratt & Whitney by Volvo Aero Corporation in Sweden. The hub was first installed on an MD-88 engine for Delta at the Pratt and Whitney factory six years before the accident. Less than two years later, the engine and fan hub were removed from its Delta aircraft at 4,456

cycles following foreign object damage (FOD) to the fan blades. The 34 blades were removed and the hub was visually inspected. The hub has 24 tierod holes (2.91 inches deep) and 24 smaller diameter stress redistribution holes. Delta maintenance personnel told NTSB investigators that the inspection was performed according to the manufacturer's procedures, which directed inspection of "all holes" in the hub for cleanliness, nicks, dents, scratches, and corrosion pits using a white fluorescent light and a three-power magnifying glass. No reworking of the part occurred after the inspection. NTSB investigators later attempted to inspect holes using these methods and noted that the limited focus of the magnifying glass and glare from the white light prevented them from viewing details of the hole walls.

The accident fan hub was installed on another engine three months later where it remained for three and one half years, accumulating a total of 12,693 cycles. The hub underwent "heavy maintenance" at that time in accordance with Delta's engine maintenance management plan. This included a fluorescent penetrant inspection (FPI) and visual nondestructive testing (NDT), a blade slot dimensional inspection, and blade slot shotpeening at Delta's Atlanta maintenance facility. The fan assembly was balanced and installed on the accident engine six months prior to the accident and was operated in a test cell. All vibration parameters were within limits. The engine was installed on the accident aircraft a couple of days later and operated without any reported anomalies until the accident. The engine did use 54 pints of oil in the month prior to the accident, but that was within the normal consumption rate according to the manufacturer. The fan hub accumulated an additional 1,142 cycles since the FPI and visual inspection.

#### Additional Information:

Post-accident metallurgical examination of the failed fan hub revealed high frictional heat and deformation at the surface of the tierod holes. The temperature reached at least 1,200 degrees F for titanium recrystallization. Iron was also found in this layer of altered microstructure. The NTSB believes that this deformation was formed during the drilling process of the tierod holes. Volvo test drillings after the accident produced similar results. Test drilling was conducted without coolant, and at higher drill revolution and feed speeds, which promoted drill breakage and the accumulation of chips in the tierod holes. Volvo reported that this altered microstructure can be created during the rough initial drilling, but not during subsequent boring and honing operations. The NTSB, considering that a total failure of the drill coolant channel should have been easily discovered during manufacturing, thought it most likely that a broken drill chip temporarily blocked the flow of coolant to generate the high temperatures. The number of fatigue striations found in the fatigue fracture region roughly equated to the number of the hub's flight cycles, indicating that the crack started almost immediately after the hub was put into service six years before the accident.

Pratt & Whitney approved Volvo's request to use a coolant channel drill because engineering data indicated that changes in drilling operations were "insignificant" as long as subsequent boring and honing operations were carried out to a depth of at least .010 inch to remove material (including defects) created by the drilling phase. NTSB metallurgical examination of the accident hub revealed that the drill altered the

microstructure to a depth of .024 inches, more than twice the anticipated Pratt & Whitney .010-inch limit.

The NTSB's BEA (Blue Etch Anodize) test on the sectioned accident hub revealed a dark blue indication in the areas of the altered microstructure. However, the hub passed Volvo's BEA and visual inspections following the original drilling process. The NTSB concluded that although the defect was detectable by BEA inspection methods, Volvo did not identify it as rejectable because the appearance did not match any of the existing templates showing rejectable conditions. After this accident, four new templates were added to assist in defect identification. The NTSB recognizes that the BEA process places interpretive demands on the inspectors and that identification of rejectable conditions may still not be complete, even with additional templates.

The crack was not likely detectable during Delta's visual inspection four years before the accident. The crack would have been about 0.1 inches deep and 0.2 inches long, but using the magnifying glass and white fluorescent light would have reduced the probability of detection compared to utilizing a more effective borescope inspection.

The FPI inspection conducted eight months and 1,142 cycles prior to the accident should have detected the crack, however. Based on striation count, the crack on the aft hub surface adjacent to the tierod hole was about 0.46 inches long and extended about 0.90 inches within the tierod hole, for a total surface length of 1.36 inches. The probability of detection, based on the Nondestructive Testing Information Analysis Center (NTIAC), was 95 percent. The crack length was well above the NTIAC minimum detection level of 0.10 inch and the FAA's Titanium Rotating Components Review Team (TRCRT) 0.08-0.10 inch range. The NTSB was unable to determine exactly why the crack was not detected during the FPI at Delta, but theorized that either (1) the FPI process was compromised by improperly performed or inadequate procedures (making the crack less or not visible), or (2) that the crack was visible, but overlooked or discounted by the inspector as insignificant:

- (1) Possible procedural factors affecting FPI preparation and inspection at Delta and other maintenance facilities include:
  - a. The FAA's post accident report on Delta's FPI process indicated that there was no assurance that parts received by FPI operators were "clean enough for an adequate FPI". The report further noted that cleaning personnel were not made aware of the critical nature of their task. The accident hub inspector indicated that he frequently had to send back parts for additional cleaning. Delta modified its training for cleaning personnel following the FAA's technical review and was working with engine manufacturers to develop cleaning standards for specific parts.
  - b. At the conclusion of the cleaning process, parts were immersed in a "hot water rinse" and flash dried. The dye penetrant will not enter the cracks if any water remains. For the flash drying process to be effective, the part must be heated to the temperature of the water (between 150 and 200 degrees). The water temperature was only

checked on a weekly basis and operators determined the temperature of parts by “feel” instead of using a temperature measuring device. Although it could not be determined if water was actually trapped in the accident hub fatigue crack, experienced practitioners and producers of the FPI process, hardware, and chemicals testified that flash drying alone may not be effective and that deep cracks will probably retain water. The NTSB concluded that significant questions exist about the reliability of flash drying in removing water from cracks.

- c. Application of developer powder (after drying) by spray gun applicator, or even a squeeze bulb, may not ensure adequate coverage of hole walls, resulting in nondetection of an otherwise detectable crack.
- d. NTSB observers found that Delta had no formal logging procedure to identify parts ready for inspection (inspection must occur within 2 hours of the application of developer powder and are even considered questionable after one hour). Delta personnel relied on “group knowledge” of how long a part had been ready for inspection. The NTSB was concerned that Delta had timing requirements in its process standard but failed to provide its personnel with a way to adhere to them. Although the NTSB did not conclusively determine that this played a role in the failed crack detection of the accident hub, the NTSB did consider the lack of a formal tracking process a significant deficiency. Delta formalized status board tracking after the accident.
- e. During the FPI process, processors and inspectors used their hands to lift and turn hubs to access different areas. FPI experts testified that the penetrant could be rubbed off during handling making crack detection difficult. Although not a determined factor, the NTSB believed that manual handling increased the opportunity to smear indications.

(2) Possible factors affecting inspector performance when a crack is visible:

- a. Personal or physical factors may affect an inspector’s ability to notice a crack. The FPI inspector in this case, however, was considered capable, competent, and had no personal or physical factors that would have prevented him from detecting a crack. The inspector passed the vision exam three months prior, was in good health, and worked stable hours.
- b. To detect a bright fluorescent green indication against a dark purple background, an inspector would have to systematically study all areas of the hub. Systematic scanning is difficult and vulnerable to human error. Previous research on visual inspections of airframe components demonstrated that cracks were missed by failure to scan an area. Following interruptions, inspectors may also not resume their inspection at the appropriate location. It is also possible that the inspector noticed the crack, but forgot to diagnose or reinspect the location. In sum, the inspections are vulnerable to errors in visual

search and are dependent on the inspector's memory to ensure that an exhaustive search and adequate followup has been conducted. The NTSB believes that a method is needed to note on the part, or document during the inspection, the portions that have been inspected and those that need further inspection.

- c. FPI inspectors have a low expectation of finding cracks and may have decreased vigilance. FPI preliminary indications are often later found not to be cracks. The accident hub inspector and supervisor both could not recall ever finding a crack on a -219 hub, therefore, the inspector's experience diagnosing indications consisted of a series of false indications. The NTSB concluded that a low expectation of finding a crack might cause an inspector to either overlook or minimize the significance of an indication. The low expectation may also decrease vigilance. The accident hub inspector described the process as tedious and monotonous and stated that he spent about 75 percent of his shift inspecting parts. He also stated that it took between 40 minutes and two hours to inspect a -219 hub, depending on the number of indications detected.
- d. It is also possible that the inspector detected the crack but did not properly complete the follow up diagnostic procedure. Delta's Process Standard was to wait at least 5 minutes to confirm that an indication had not reappeared after developer was applied during the bleed out procedure. As noted already, there was no formal method for inspectors to track these indications or to ensure that they were reinspected after the required redevelopment period.
- e. Lack of training for inspectors was considered, but the accident hub FPI inspector had completed a formal training program that included written and practical exams and his training was consistent with industry standards. However, since this accident crack was not detected at a repair facility that followed industry standards, the NTSB issued a Safety Recommendation to the FAA to review and revise those standards.

Because the FPI is dependent on several individuals performing multiple procedures, no single reason for the nondetection of the crack was identified. The NTSB concluded that Delta's nondetection of the crack was caused by either a failure of the cleaning and FPI processing, a failure of the inspector to detect the crack, or some combination of these factors.

Following the United Airlines' Sioux City DC-10 accident (seven years earlier), the FAA formed the TRCRT to assess quality control procedures used in the manufacture of titanium alloy high-energy rotating turbine engine components. The TRCRT final report made several recommendations, including using eddy current inspections to supplement FPIs and a requirement to submit parts to at least two "subsurface inspections" (e.g., ultrasonic) during their cyclic life. However, the implementation schedule was canceled by the FAA following an industry conference in which representatives requested that the

schedule be modified. The NTSB was disappointed that no new schedules were developed and that no further action was taken by the FAA to implement the TRCRT report recommendations.

Has anything like this happened before? Yes. Several times. Two examples:

1. Inability to see cracks in critical rotating parts, because of handling and methods used to support the parts (cables), was a consideration in the United DC-10 accident in Sioux City.
2. Lack of proper inspection methods and training was cited in a missed ½ inch crack preceding a ValuJet uncontained engine failure.

These, and other part failures, were all subjected to one or more nondestructive inspection techniques (such as etch, ultrasonic, or FPI). However, the cracks were not detected and the parts passed inspection. The NTSB concludes that the manufacturing and in-service inspection processes used did not provide sufficient redundancy.

NTSB Conclusions:

1. The flightcrew was properly certified and trained for the flight, and was in compliance with Federal flight and duty time regulations.
2. The airplane was properly certificated and maintained in accordance with applicable Federal regulations, including a Federal Aviation Administration-approved airworthiness maintenance program.
3. Visual meteorological conditions prevailed, and weather was not a factor in the accident.
4. The oil observed preflight by the first officer came from the No. 1 bearing housing and, therefore, was not a precursor to the accident.
5. Some form of drill breakage or drill breakdown, combined with localized loss of coolant and chip packing, occurred during the drilling process, creating the altered microstructure and ladder cracking in the accident fan hub.
6. Fatigue cracks initiated from the ladder cracking in the tierod hole and began propagating almost immediately after the hub was put into service in 1990.
7. Although the altered microstructure in the accident hub tierod hole was detectable by blue etch anodize inspection methods, Volvo did not identify it as rejectable because the appearance of the tierod hole did not match any of the existing inspection templates showing rejectable conditions.
8. Although the additional templates will assist blue etch anodize inspectors in detecting potential defects similar to the one that existed on the accident hub, this accident suggests that there may be additional rejectable conditions that have not yet been identified.
9. Drilling damage in this accident hub extended much deeper into hole sidewall material than previously anticipated by Pratt & Whitney.
10. The crack was large enough to have been detectable during the accident hub's last fluorescent penetrant inspection at Delta.
11. Significant questions exist about the reliability of flash drying in removing water from cracks.
12. Better techniques are needed to ensure the fullest possible coverage of dry developer powder, particularly along hole walls.

13. Although it could not be conclusively determined whether this played a role in the nondetection of the crack in the accident hub, the absence of a system that formally tracks the timing of the movement of parts through the fluorescent penetrant inspection process was a significant deficiency.
14. Fluorescent penetrant inspection indications remain vulnerable to manual handling, and fixtures used to support the part during inspection may obstruct inspector access to areas of the part.
15. One or more procedural deficiencies in the cleaning, drying, processing, and handling of the part might have reduced or prevented the effectiveness of Delta's fluorescent penetrant inspection process in revealing the crack.
16. The potential deficiencies identified in the Delta fluorescent penetrant inspection process may exist at other maintenance facilities and be, in part, the reason for the failure to detect cracks in other failed engines identified in this investigation.
17. No personal or physical factors would have prevented the FPI inspector from detecting a visible crack in the accident hub.
18. An inadvertent failure of the inspector to systematically search and complete followup diagnosis when necessary on all surfaces of the hub might have caused the FPI inspector to overlook the crack.
19. A low expectation of finding a crack in a -219 series fan hub might have caused the FPI inspector to overlook or minimize the significance of an indication.
20. The duration of inspections and the amount and duration of rest periods may indeed affect inspector performance, but this potential has not been adequately studied in the aviation domain.
21. Because of the potentially catastrophic consequences of a missed crack in a critical rotating part, testing methods that evaluate inspector capabilities in visual search and detection and document their sensitivity to detecting defects on representative parts are necessary.
22. Delta's nondetection of the crack was caused either by a failure of the cleaning and fluorescent penetrant inspection processing, a failure of the inspector to detect the crack, or some combination of these factors.
23. Manufacturing and in-service inspection processes currently being used do not provide sufficient redundancy to guarantee that newly manufactured critical rotating titanium engine parts will be put into service defect-free and will remain crack-free through the service life of the part. Further, all critical rotating titanium engine components are susceptible to manufacturing flaws and resulting cracking and uncontained engine failures that could potentially lead to catastrophic accidents.
24. Although during the preflight inspection the first officer found a small amount of oil on the bullet nose of the left engine and two missing rivets, these were not factors in the subsequent engine failure.
25. There is a lack of clarity in written guidance in the flight operations manual to Delta flightcrews on what constitutes maintenance "discrepancies" and "irregularities" and when to contact maintenance personnel and to log anomalies.
26. The captain shut down the engines in a timely manner when he became aware of conditions in the aft cabin.
27. Neither the aft flight attendants' decision to evacuate nor the captain's decision not to evacuate was improper in light of the information each of them had available at the time.

28. Every passenger-carrying airplane operating under 14 Code of Federal Regulations Part 121 should have a reliable means to ensure that all crewmembers on board the airplane are immediately made aware of a decision to initiate an evacuation.
29. Safety could be enhanced if all cockpit crews were immediately made aware of when exits are opened during an emergency.
30. Guidance provided to passengers on Delta Air Lines MD-88s regarding when emergency exits should and should not be opened is not sufficiently specific.

NTSB Probable Cause:

The National Transportation Safety Board determines that the probable cause of this accident was the fracture of the left engine's front compressor fan hub, which resulted from the failure of Delta Air Lines' fluorescent penetrant inspection process to detect a detectable fatigue crack initiating from an area of altered microstructure that was created during the drilling process by Volvo for Pratt & Whitney and that went undetected at the time of manufacture.

NTSB Contributing Causes:

Contributing to the accident was the lack of sufficient redundancy in the in-service inspection program.

## **PRESENTATION FOUR**

# **Risk Assessment**

**Objective:** This presentation introduces the student to the process of Risk Assessment and the prioritization of risk interventions.

Slide 1



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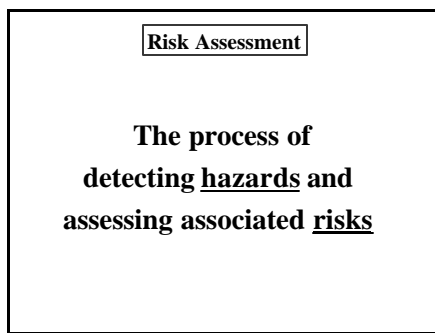
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Slide 2



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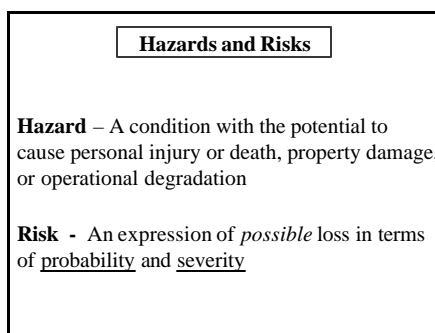
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Slide 3



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Slide 4



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Slide 5

**Assessing Hazards by Probability**

**Probability**  
How often will a certain hazard lead to an accident?

<b>Frequent:</b>	Probably will occur very often
<b>Likely:</b>	Probably will occur often
<b>Occasional:</b>	Expected to occur occasionally
<b>Seldom:</b>	Expected to occur on a rare basis
<b>Unlikely:</b>	Unexpected, but might occur

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Slide 6

**Assessing Hazards by Severity**

**Severity**  
When that hazard does cause an accident, how severe will the outcome be?

<b>Catastrophic:</b>	Loss of life; complete equipment loss
<b>Critical:</b>	Accident level injury and equipment damage
<b>Moderate:</b>	Incident to minor accident damage
<b>Negligible:</b>	Damage probably less than accident or incident levels

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Slide 7

Combining Probability and Severity

# RISK

**Extremely High Risk:**  
A hazardous condition may cause *frequent* accidents which may result in *catastrophic* equipment losses, injury, or death.

**Low Risk:**  
A hazardous condition is *unlikely* to cause accidents, and even if it does, results in only *negligible* damage.

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Slide 8

Risk Elimination?

All accident causal factors (hazards) should be eliminated, however, we may not have the resources to immediately accomplish it.

We must then prioritize our corrective actions by addressing **High Risks** before **Low Risks**.

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Slide 9

Risk Assessment

But, how can we systematically classify and prioritize risks?

Answer: Risk Assessment Codes or (RACs). They provide a simple method to prioritize intervention strategies.

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Slide 10

Risk Assessment Matrix						
RAC Codes		PROBABILITY				
		Frequent	Likely	Occasional	Seldom	Unlikely
		A	B	C	D	E
SEVERITY	Catastrophic	I	Extremely High	IB		
	Critical	II		High	IID	
	Moderate	III	IIIA	Medium		Low
	Negligible	IV		IVB		IVE

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Slide 11

RAC Example



Inappropriate equipment was used to wash an aircraft.

**Inadequate Brushes**  
Damage to aircraft/people from brushes would be *Negligible* (IV).  
Accidents are *Unlikely* from using inappropriate brushes (E).

RAC Code is IVE...a Low Risk.

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Slide 12

RAC Example



What if goggles were not used during the aircraft wash?

**Lack of Goggles**  
Damage to the aircraft is certainly *Negligible*, but eye injuries could be *Critical* (II). Not using goggles on aircraft washes may cause eye accidents (*Seldom-D*).  
Critical II and Seldom D: RAC IID - A Medium Risk.

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Slide 13

RAC Example



Task Change: Welding, without goggles!

Damage to the aircraft components could be *Moderate*, but eye injuries could be *Critical (II)*. Not using goggles during welding will *Frequently (A)* cause accidents.  
Critical (worst case) II and Frequent A: RAC IIA  
An Extremely High Risk!

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Slide 14

Risk Assessment Matrix

		PROBABILITY				
		Frequent	Likely	Occasional	Seldom	Unlikely
		A	B	C	D	E
SEVERITY	Catastrophic I	Extremely High				
	Critical II	Welding IIA			High	Goggles IID
	Moderate III		Medium			Low
	Negligible IV					Brushes IVE

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Slide 15

Case Study: HFACS-ME with RACs



An unsupervised electrician was told to conduct some aircraft electrical repairs. A “seasoned pro”, he decided that it wasn’t necessary to secure power or use tags for such a small job. Unable to trace the wires adequately in the dark, confined area with his flashlight, he decided to disconnect the most likely of several wires. The electrical short destroyed several pieces of equipment.

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Slide 16

HFACS-ME Analysis				
Error Categories of HFACS Framework				
First Order	Second Order	Third Order		
Management Conditions	Organizational	- Inadequate Processes	- Inadequate Documentation	- Inadequate Design
		- Inadequate Resources		
	Supervisory	- Inadequate Supervision	- Inappropriate Operations	- Uncorrected Problem
Maintainer Conditions	Medical	- Supervisors Misconduct		
		- Mental State	- Physical State	- Limitation
	Crew Coordination	- Communication	- Assertiveness	- Adaptability/Flexibility
Working Conditions	Readiness	- Training/Preparation	- Certification/Qualification	- Infrequent
	Environment	- Lighting/Light	- Weather/Exposure	- Environmental Hazards
	Equipment	- Damaged/Unservice	- Unavailable/Inappropriate	- Dated/Unperfected
Maintainer Acts	Workspace	- Confining	- Obstructed	- Inaccessible
		- Error	- Judgment/Decision Making	- Knowledge/Rule Based
	Violation	- Attention/Memory	- Skill/Technique	
		Routine	Flagrant	Exceptional

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Slide 17

RAC Codes	
<u>Maintainer Acts</u>	
Violation – Infraction. RAC-IA	
Error – Judgment/Decision Making. RAC-IB	
<u>Maintainer Conditions</u> - Medical – Mental State. RAC-IC	
<u>Management Condition</u> -Supervisory -Inad. Supervision. RAC-IC	
<u>Working Conditions</u>	
Equipment – Unavailable/Inappropriate. RAC-ID	
Environment – Lighting/Light. RAC-ID	
Workspace – Confining. RAC-III	

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Slide 18

Risk Assessment Matrix						
		PROBABILITY				
		Frequent	Likely	Occasional	Seldom	Unlikely
		A	B	C	D	E
S E V E R I T Y	Catastrophic I	Violation IA Extremely High	Judgment IB	Mental State/ Supervision IC	Equipment/ Lighting ID	
	Critical II		High		Confining IID	
	Moderate III		Medium			Low
	Negligible IV					

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## Slide 19

### Summary

- Risk Assessment helps organizations to analyze individual hazards by their risk potential.
- RACs provide a simple means to classify risks by their probability and severity.
- Organizations can effectively use RACs to select the appropriate intervention strategies for prevention of future accidents.

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## Slide 20

### Questions?



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**PRESENTATION FIVE**

# **Intervention Development**

**Objective:** This presentation provides guidance on Intervention Strategy Development to maximize an organization's efforts to prevent future accidents and incidents.

Slide 1

***Human Factors***  
**Intervention  
Development**



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Slide 2

**What are interventions?**

**Methods to control, mitigate, or  
eliminate the hazards which lead  
to accidents.**

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Slide 3

**Intervention Strategies**

**Error Prevention**  
Reduce, and hopefully eliminate,  
the possibility of a human error  
from occurring



**Performance Enhancement**  
Increase an individual's capacity to  
perform a given task or operation



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Slide 4

Intervention Controls

1. ENGINEERING -- Improve equipment design, work conditions, etc. to eliminate hazards.

2. ADMINISTRATIVE -- Reduce hazard exposure or control risks through standards, supervision, etc.

3. PERSONNEL -- PPE, HAZCOM, & Training.

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Slide 5

Controls are Safety Barriers

  
Engineering Controls

  
Personnel Controls

  
Administrative Controls

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Slide 6

Doing Our Very Best

Despite our best efforts:

➤ It is impossible to engineer every hazard out (though designs are consistently improved)

➤ Policies are also imperfect

➤ Program or individual shortfalls in training, nutrition, health, professional development

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Slide 7

Intervention/Control Failures

➤ Control is inappropriate

➤ It is misunderstood

➤ Operators may dislike it

➤ Supervisors may dislike it

➤ It turns out to be too costly

➤ Overcome by other priorities

➤ Not monitored for effectiveness

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Slide 8

Human Factors  
Intervention Strategy Matrix

Engineering ControlAdministrative ControlPersonnel Control

Error Prevention

Performance Enhancement

X	X	

Most Mishap Recommendations Fall into Just Two Categories!!!!!!

"We Need to Start Thinking Out of the Box"

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Slide 9

Examples "Inside the Box"

Engineering ControlAdministrative ControlPersonnel Control

Error Prevention

Performance Enhancement

X	X	

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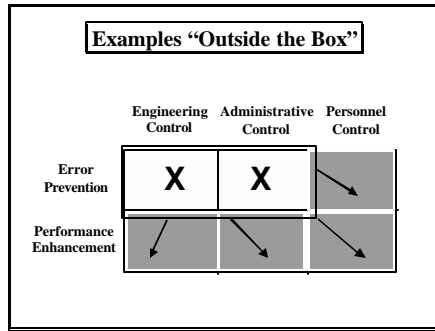
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Slide 10



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Slide 11

**Summary**

- Intervention strategies must be expanded to consider more than just error prevention
- Interventions must be properly implemented and monitored to ensure their ultimate effectiveness in controlling error
- Open reporting is critical to effective human error identification and intervention development
- Transgressions must be recognized as human errors and consequently reported, analyzed, and controlled

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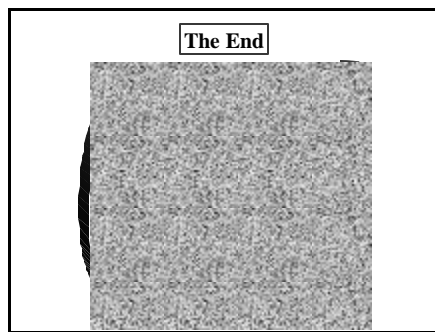
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Slide 12



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## WORKSHOP

# Maintenance Error Analysis/ Intervention

**Objective:** This workshop introduces the student to the practical applications of the Human Factors Analysis and Classification System – Maintenance Extension (HFACS-ME) framework, the Risk Assessment Process, and the development of successful Intervention Strategies. Two case studies are provided to build the skills and confidence to use HFACS-ME effectively for the investigation and analysis of both accidents and incidents.

# **Intervention Control Workshop**

## **Case Study # 1**

### **EMB-120 In-flight Structural Breakup**

The first leg of the commuter flight was without incident. The second leg also proceeded smoothly to its cruising altitude of FL240. However, during the descent through 11,800 MSL, a sudden pitch over occurred. The FDR revealed that the engines were operating normally until that time and no evidence exists of engine or propeller defect or anomaly prior to the unusual attitudes and in-flight breakup. Eight eyewitnesses who saw the airplane's final moments described an in-flight breakup and fire, wing failures, the sounds of engines revving and sputtering, and a flat spin. The aircraft impacted the ground upright in a wings-level attitude. All persons onboard were killed and the pilots were found still strapped into their seats.

Shortly after the accident, a passenger that had been on the first leg of the flight stated that he was awakened by vibrations that rattled his beverage can on the meal tray. He asked the flight attendant if he could move to another seat, but did not inform the attendant or any crewmembers about the vibrations. Other passengers on that first leg did not recall any unusual vibrations.

The NTSB discovered that the T-tail (horizontal stabilizer) separated from the fuselage first, causing C.G. shifts and subsequent aerodynamic loading failures to the remaining structure. Forty-seven screw fasteners were discovered missing from the upper surface of the T-tail's leading edge assembly. They had been removed the night before during routine maintenance on the horizontal stabilizer deice boots.

#### **General Data:**

Fatalities: 14 (all onboard)

Weather: Visibility 6 miles, haze, no significant weather conditions

Time: 10:03 am

CG Limits: Well within limits

Airspeed limits: The aircraft was 12 knots below the upper limit when the pitch over occurred

Peak negative G force: Unknown - Surpassed FDR's recording limit of -3.375 G's.

AD Compliance: No discrepancies were noted with AD compliance.

#### **Personnel Data:**

The Captain, age 29, had 4,234 total flying hours (2,468 in the EMB-120).

The First Officer, age 43, had 11,543 total flying hours (1,066 in the EMB-120).

The Management and Maintenance Personnel: No evidence of alcohol or drug abuse was found during tests on the maintenance personnel, and the NTSB noted no unusual background or behavioral issues.

#### Maintenance Background:

Two weeks prior to the accident, a quality control inspector noted that both leading edge deice boots had dry rotted pin holes. The airline's Maintenance Control scheduled the replacement of both deice boots for the night before the accident. Work began during the evening (second) shift at 2130.

The horizontal stabilizer's leading edges must be removed to facilitate the boot replacement. The leading edge/deice boot assembly is attached to the stabilizer with approximately 47 attaching screws for each of the top and bottom sides of the assembly.

The T-tail, which is approximately 20 feet above the ground, was accessed by using a hydraulic work platform. Two evening shift mechanics removed most of the screws on the bottom right leading edge and partially removed its deice boot. An inspector assisted the mechanics by climbing on top of the T-tail to remove the screws on both of the upper right and left sides. He placed the useable screws in a bag, and discarded the rest. The bottom left side screws were not removed. The inspector, age 25, had received company discipline on two occasions related to inspections the previous month. He was given warnings for having "missed a crack...in an inspection of engine exhaust stack" and also because he "did not finish all paperwork required...missed 15 task cards on the accountability sheet."

Following a shift change to the midnight (third) shift, the right leading edge assembly was eventually removed and a new deice boot was bonded onto it. The entire task had originally been assigned to the third shift, but the second shift supervisor elected to start the work to assist the third shift with their workload. However, because the card package was assigned to the third shift, the second shift supervisor decided not to issue the work cards to his mechanics. As a result, no entries were made on the reverse side of the M-602 work cards that would have informed the third shift that work had been started on both the left and right stabilizer. The third shift maintenance supervisor and mechanics also were not verbally informed of the removal of the left side assembly's upper screws.

The third shift inspector had arrived early and reviewed the inspector turnover form, but found no write up because the second shift inspector who had removed the upper screws had not yet made his log entries. The second shift inspector did not conduct a verbal turnover with this oncoming inspector. He simply filled out the turnover form with "helped the mechanic remove the deice boots", then clocked out and went home. He later stated that he placed the screws that he removed from the top of both sides of the stabilizer in a bag and left it on the man lift.

A second shift mechanic (who was removed earlier from the deice boot task to conduct a C check on another airplane) gave a verbal turnover about the accident aircraft to his C check supervisor (who was not in charge of the accident aircraft). The C check

supervisor, however, did not inform the oncoming third shift supervisor about this new information (he had already briefed him prior to this) and he did not fill out a maintenance shift turnover form. He instead told his mechanic to give the turnover to a third shift mechanic, which he then did. This third shift mechanic, however, did not get assigned to the accident aircraft after the brief, but he did recall seeing the bag of screws on the man lift. So this third shift mechanic then gave a verbal turnover to another third shift mechanic, who later stated that he did not recall receiving a turnover. When yet another third shift mechanic arrived, his supervisor told him to find the second shift supervisor to get a turnover on the boot replacement. As he was not told which second shift supervisor to talk to, he ended up talking to the second shift C check supervisor. That supervisor did tell him that the crew that worked the right side earlier had a few stripped screws that prevented them from removing the right leading edge. When the mechanic asked if any work had been performed on the left deice boot, the supervisor informed him that he did not think that he would have time to change the left deice boot that evening.

The second shift supervisor who was responsible for the aircraft then left work without talking to the other second shift supervisor, the third shift supervisor who was working in the hangar, or the third shift supervisor in charge of line checks.

The third shift supervisor left the hangar to work at the gate and had no involvement with the accident airplane.

During this third shift and prior to work completion, the airplane was pushed out of the hanger to make room for work on another airplane. Although the bonding for the right stabilizer was accomplished on a bench in the hangar, the reattaching work was resumed outside. The mechanics did find the bag of screws, but used both new and old screws to reattach the assembly. One of them stated that although there were approximately a dozen screws left over on the man-lift, he did not think this was significant because of the number of screws he had to replace due to drilling out and corrosion.

There was no direct light placed on the airplane while outside the hangar. The third shift inspector gained access to the top of the horizontal stabilizer to assist with the right side deice line installation, but he was not told of any removed screws from the left side and did not notice them missing in the outside darkness.

The aircraft was then cleared for its 0700 passenger flight. There is no evidence to show that the flight crew knew of any work performed on the stabilizer. There was no indication of stabilizer work in the pilot's airplane logbook because it was considered routine maintenance work. Moreover, the FARs and airlines did not require them to be informed of such work.

#### Other useful information:

The aircraft's stabilizer is a Required Inspection Item (RII). A Quality Assurance inspector must conduct a concentrated inspection on any work listed as an RII item. The

airline's management and quality control inspectors stated that the deice boots were not RII items, however. This disagrees with their own deice boot work cards which had the RII "yes" block circled. A QA inspector on the third shift did sign off the work on this aircraft, but because he knew that the boot was not really an RII item, he only conducted a cursory walk around the tail without inspecting the final installation of the leading edge/deice boot.

The manufacturer stated that the deice boots and leading edges, as assemblies, were RIIs. The airline's management maintained that if the manufacturer or the FAA wanted the assembly treated as an RII or critical item they should have made that clear. The NTSB believes that the boot by itself is not an RII item, but with the necessary removal of the stabilizers leading edge to facilitate installation, it should be designated as an RII procedure.

Although not a factor, the aircraft had elevator-balancing work done four months earlier following a lightning strike. The mechanic stated that because balancing equipment was available, but apparently misplaced, he used "homemade" balancing blocks on a level table and visually confirmed the balance of the elevator. This was not an FAA approved method, but the manufacturer later stated that it would only have had a negligible effect of less than 1 percent on the balance.

An over torque condition with a required propeller change occurred one year prior to this accident. Although it also was not deemed a factor in this accident, the review of maintenance records revealed that the manufacturer's maintenance procedures were again not followed. There was also no engine logbook entry of an over torque and no record to verify that the engine could remain in service.

The NTSB concluded that the airline's GMM incorporated the FAA-approved procedures for shift turnovers and noted no other specific deficiencies with the document. If followed, the NTSB believed that it could have prevented the accident. The inspectors were found to be some of the worst offenders in following company procedures. The NTSB believed that since the correct procedures were generally known, but not used, that management did not establish an effective safety orientation for its employees, which contributed to their lax attitude.

The former FAA Principle Maintenance Inspector (PMI) was subjected to tremendous workload that limited his effectiveness in monitoring safety. Under his 2 ½ years as PMI, which ended only two months prior to the accident, the airline expanded from 45 to 101 airplanes through mergers. He stated that he was the sole inspector at the airline's headquarters during which time he had other certificate responsibilities. He also had to train an assistant and acquired additional responsibilities during the airline's entry into bankruptcy protection. He could keep up with the number of inspections, but the quality suffered. The new PMI stated that he had to work evenings and weekends to fulfill all of his responsibilities. Because of their limited observance of the shop floors, the FAA inspectors relied more on paperwork records, but that would not have helped in this accident, as the paperwork was not completed by the mechanics.

NTSB Conclusions:

1. All crewmembers and air traffic controllers were properly certified.
2. No preflight or accident flight crew factors were discovered.
3. No air traffic control factors were causal to the accident.
4. Weather was not a factor.
5. There were no engine or flight control malfunctions.
6. The aircraft was within its operating airspeed envelope when the stabilizer failed.
7. The airplane pitched severely nose down upon the loss of the horizontal stabilizer and the wings stalled negatively.
8. The violent motion of the airplane and the extreme air loads following the loss of the horizontal stabilizer leading edge caused the airplane to further break up in flight.
9. An in-flight fire occurred during the breakup.
10. The leading edge failed because the upper row of screw fasteners (47 screws) were not in place and the airflow cause the surface to bend down and separate.
11. The fasteners were removed for scheduled maintenance the night before the accident and a breakdown in procedures failed to detect the work was incomplete.
12. The airline's General Maintenance Manual (GMM) contained adequate procedures for maintenance and quality control.
13. There was a lack of compliance in the GMM by the mechanics, inspectors, and supervisors responsible for the aircraft.
14. The lack of compliance with the GMM allowed an unairworthy airplane to be returned to scheduled passenger service.
15. The replacement of the deice boots should be treated as a Required Inspection Item (RII) to require proper quality control procedures.
16. The airline previously failed to follow established requirements for performing maintenance during repairs of the elevator and engine overtorque (not causal to this accident).
17. The maintenance deficiencies noted indicate that the airline's management failed to instill an adequate safety orientation in its maintenance personnel through adherence to procedures.
18. The FAA's routine surveillance of the airline was inadequate and did not detect deficiencies such as those that led to this accident.
19. The accident was not survivable.

NTSB Probable Cause: The failure of [the airline's] maintenance and inspection personnel to adhere to proper maintenance and quality assurance procedures for the airplane's horizontal stabilizer deice boots that led to the sudden in-flight loss of the partially secured left horizontal stabilizer leading edge and the immediate severe nose-down pitch over and breakup of the airplane.

NTSB Contributing Causes: (1) The failure of [the airline's] management to ensure compliance with the approved maintenance procedures, and (2) the failure of FAA surveillance to detect and verify compliance with approved procedures.

NTSB Dissenting Statement:

One NTSB member filed a dissenting statement to include another factor on the absence of a Lead Mechanic and a Lead Inspector as specified in the GMM. Senior management's failure to fill these positions diffused and diluted the chain of authority and accountability among the maintenance personnel. This member felt that this situation, more than any other single factor, was directly causal to the accident.

# **Intervention Control Workshop**

## **Case Study # 2**

### **Boeing 747 Engine Strikes Runway**

The aircraft's No. 1 engine struck the runway when it partially separated from the wing during landing rollout at an intermediate stop airport. The flight, touchdown, and initial rollout were normal. Engine thrust reversing was also normal on all four engines until the flight crew moved the engine power levers out of reverse at 90 knots. The engine and pylon then rotated downward about the midspar pylon-to-wing fittings. The lower forward engine nose cowl was ground away as it was dragged along the runway. A fire near the engine was rapidly extinguished by the local fire fighters. All passengers remained onboard and were deplaned about 30 minutes later. There were no injuries.

The primary forward upper link fuse pin was later found fractured within the No. 1 engine's pylon. It failed in an overload condition. There was no evidence of preexisting fatigue.

Prior to this landing, the aft fuse pin on the No.1 engine pylon diagonal brace had migrated out of its fitting. It was found after the accident within the pylon structure, intact, undamaged, and with no preexisting defects. The aft diagonal brace fuse pin is normally retained by both a primary retainer (washer style caps and bolt) and a secondary retention clip (a bolt-on C-shaped bracket). Neither retention device was located in the aircraft or found on the runway.

The aircraft had accumulated 14 flight cycles since its most recent "C" check about eight days prior. The day after the accident, airline personnel advised the NTSB that a set of primary and secondary retainers had been found at the maintenance facility in an unmarked white cloth bag. The bag was found between the handrail and a "2x4" on the left under-wing stand that was used for the "C" check of the accident aircraft. The "C" check included maintenance and inspection of the diagonal brace fuse pins.

#### **Background Maintenance Information:**

The airline's General Engineering and Maintenance Manual (GEMM) contained the policies and general operating procedures, including work control procedures, paperwork, etc.

The airline's Centralized Interactive Text System (CITEXT) system had been incorporated through a merger 8 years earlier. It replaced the hard copy, manually generated maintenance system with new CITEXT-generated work cards that followed the instructions in the manuals. The airline estimated that 95 percent of its routine maintenance procedures were generated by CITEXT. The NTSB found numerous problems with the airline's CITEXT, including duplication of tasks, conflicts with the airplane maintenance manual and the lack of graphics and charts. All of the mechanics

interviewed stated that they continued to refer to the maintenance manuals while using CITEXT. Improvements to the CITEXT cards were ongoing, however. Airline managers, lead mechanics, and publication and maintenance staff members composed a group that met regularly to correct the CITEXT discrepancies. The airline's general inspectors were not part of that group, however.

Maintenance training consisted mostly of OJT and there was no regularly scheduled classroom training. A one-day familiarization-training program was established two years earlier for new mechanics. Lead mechanics were responsible for training their subordinates. The airline had seven instructors for 747/DC10 maintenance training and a Director of Training, although that position was vacant at the time of the accident and was being filled by a temporary director.

Non-routine maintenance was supposed to be identified with a numbered, red tag. The maintenance and inspection personnel interviewed by the NTSB gave inconsistent answers on implementation of the red tag policy, including differences on who could generate the tags and whether the tags were even required if the work could be completed prior to the end of each shift. Red tag procedures were mostly taught through OJT.

#### The Maintenance on the Aircraft:

Mechanics were scheduled to prepare for non-destructive testing (NDT) of the diagonal brace lugs and other work inside the No. 1 pylon as part of a "C" check. CITEXT work cards were generated for the task. Step 4 of the task card specified removal of the secondary retention device to allow room to maneuver the ultrasonic transducer, but it did not call for removal of the primary retention through-bolt and washers. A mechanic accomplished the task as described and initialed the card. He did not use a red tag because none was required by the CITEXT card. Although he had no training on when to use tags, he stated that red tags were not required for removal of secondary retainers, but they are required for primary pin removal. The mechanic added that he was unaware of who was supposed to reinstall the retainers following the NDT inspection. He had conducted this type of task 50 to 100 times.

The airline NDT inspector was assigned to inspect both the No.1 and No.4 diagonal brace fittings. He used the same work cards as the mechanic previously mentioned. He confirmed the primary retention bolts were in place and the secondary retainers were removed per the CITEXT card. The NDT inspector also stated that he had not recognized that the secondary retainers were required on this airplane. He marked "N/A" on step 10 of the card, which stated "Reinstall fuse pin secondary retainers at forward and aft lug locations if removed per step 4 above." The NTSB believes that writing N/A in step 10 was an error. The card allows an "N/A" to be placed in steps 8 and 9 if no cracks were found in step 7, but it was incorrect to continue and label steps 10 and 11 with "N/A". The NTSB was unable to determine why he marked the card that way and speculated that the inspector merely completed the card inattentively. He performed the No.1 pylon ultrasonic inspection in the afternoon and the No. 4 earlier in the morning.

The B747-200 aircraft could have either of two different types of pylon retention fuse pins installed. The CITEXT card did not have any information that would alert the mechanic to the type of pin in use on a particular pylon. Step 4 of the card only called for the removal of the secondary retainer “if installed”. Although the “removal” step would be obvious, the necessity for reinstallation may not. A maintainer would have to perform a close inspection of the pin to determine which generation of pin was installed. Only the second generation fuse pins required secondary retainers. Maintainers had no guidance available for determining which pin generation it was and no method of feedback to indicate whether the determination was correct.

The NTSB learned that the No. 1 diagonal brace aft fuse pin (as opposed to a retainer) was removed for maintenance after the NDT inspection. The mechanic responsible for this activity told the NTSB that he was assigned to check for and remove rust in the area of the No. 1 pylon upper link. He found no rust, but did find a migrated upper link bushing, so he generated a nonroutine work card to rework the bushing. The bushing repair required removal of the No. 1 diagonal brace aft fuse pin, as well as the upper link. The mechanic noted that neither the primary or secondary retention devices were in place when he removed and reinstalled the fuse pin. [The NTSB never identified the person who removed the primary retainers, the reason for the removal, or why there were no red tags or work cards generated for that action]. Because he completed the work quickly, he did not complete the nonroutine paperwork or use a red tag. Most of the maintenance personnel also reported that they did not remember seeing any red tags attached to the No. 1 pylon area. No similar work was conducted on the No. 4 pylon. This mechanic was temporary manager for the week, supervising lead mechanics, some with more seniority than he had.

Two of the mechanics who closed up the No. 4 pylon were not experienced with engine and pylon work. Both were certified A&Ps, but they were normally assigned interior aircraft work. The airline had a final “OK to Close” inspection, however, that was performed before the doors and panels were closed. The inspector stated that this inspection indicated that he had examined the work area, found no red tags or other discrepancies, and signed off the work performed in that area. He qualified the description by adding that it was a quick area inspection for rags and previously identified problem areas, and that he had no specific routine for checking the pylon areas. During the final close-up, one of the two mechanics found a white bag containing the primary and secondary retainers for the No.4 pylon (as opposed to the No. 1 pylon) attached to the batwing door. An examination of the No. 4 pylon revealed that the retainers were missing, so they installed the retainers found in the bag. The aircraft was then rolled out for the operational check. The No. 1 engine and pylon had already been inspected and closed up prior to the discovery of the No. 4 retainers in the bag. There was no attempt by the inspector, the mechanics or supervisors to re-inspect the No. 1 pylon diagonal brace for similar missing retainers. [The NDT inspector, who earlier conducted the testing of the pins, stated later that he had not noticed a white bag near the No. 1 pylon].

The “OK to Close” inspection was completed at 0600, at the end of the night shift, on the sixth full night of what was supposed to be a five-day workweek. The inspector indicated that he worked about twice as hard that night, performing nearly twice the inspections of his normal routine. Also, because of the shortage of personnel on the weekend, he and one other inspector were expected to work on two 747s in both hangars 5 and 6, which required constant shifting between the hangars. The inspector felt a sense of pressure and was fatigued because he had worked all night without a break. He added that 50-75 percent of the time, the pylons are not ready for closure when inspected. He said that he has been criticized for being too critical of mechanics concerning closures, but he believes the “OK to Close” inspection is important. He added that he has never had an FAA inspector follow him during the course of his work. (A production planner of 12 years also said that he was never aware of an FAA inspection of his work). This “C” check was accomplished 4 days earlier than estimated. The work was accomplished Saturday night and the aircraft was rolled out early Sunday morning.

Additional Information:

The FAA Principal Maintenance Inspector (PMI) said that the airline was compliance oriented and that all required inspections “get done”. He added that the airline even provided a SCEPTRE terminal in his office so that he had direct access to records and other maintenance programs. The FAA Partial Program Manager (PPM) stated that he tries to visit the hangar one night a week. He observes the work accomplished and then follows the generated paperwork. He will observe, but not request that items be opened once the inspection has been completed.

Two hangars at the repair facility were dedicated to 747 maintenance. Work was performed 7 days a week using three 8-hour shifts. Bidding of desired shifts was permitted using union seniority. Of 545 maintenance personnel, 252 worked the first shift (0648-1548). The Director of Maintenance stated that there were also shift coverage problems on the weekends, with 250 people on the first shift, 130 on the second (1548-2248) and only 34 on the third shift (2248-0648). Due to low interest in weekend work, the maintenance and inspection staffs frequently did not work their usual functions. The crews were constantly changing and they worked in settings different from the accustomed routine. One mechanic stated that there was a lot of “borrowing of people” on Saturday nights and that they were usually less experienced. He believed that the overtime working conditions could lead to confusion when strangers worked together in areas that they had not previously worked. The Maintenance Director also stated that over the last year, with the signing of a new labor/management contract and with the completion of the ARMAR(aging aircraft) Program, there has been “constant movement” of mechanics across hangars and between shops, which has caused some confusion on the hangar floor. The labor contract allowed lead mechanics to come in 18 minutes early to be briefed by the previous shift; however, no formal checklist or procedure exists on briefing items. The Director also confirmed that there were specific information problems with CITEXT and that he constantly hears of procedures not being followed. He has written to managers on procedures to follow for documenting parts and using red tag procedures.

A lead mechanic noted weekend work problems, as well. He said that only two lead mechanics and two inspectors are assigned to the weekend third shift, and they must support both hangars 5 and 6. Management is usually anxious to dispatch airplanes out of the hangar on weekends, but the experience of the weekend mechanics is low. Weekend crews are made up of people from various other crews, and he did not personally know many of the people he worked with on this aircraft, or their qualifications. He also said that there were no engine mechanics on his crew. Another lead mechanic confirmed the weekend manning problems and added that mechanics could be handed multiple CITEXT cards for accomplishment. He further stated that the CITEXT cards' most common problem was incorrect part numbers and serial numbers.

The two hangars (hangars "5 and 6") had different physical work environments. Hangar 6 scaffolding utilized plywood decking with loose wood planks placed on the wing docks for bridges 8 feet above the concrete floor. The "OK to Close" inspector expressed personal safety concerns about these temporary bridges, but reluctantly used them after becoming tired while climbing up and down the adjacent platforms. The light fixtures on the wing docks were either not in use or covered with paint over spray from previous use of the hangar for painting aircraft. An inspector would have to hold onto the airplane structure with one hand, lean under the bat wing doors at more than a 30 degree angle, hold a flashlight with the other hand, and move his head awkwardly to face up into the pylon area to inspect the pin retainers. Mechanics were observed using flashlights and portable lights for underside work. In contrast, hangar 5 had permanent wing docks and adequate lighting.

The NTSB inspected hangar 6 after the accident. They observed mechanics placing parts on the floor, in various racks, and in an overfilled wooden box on top of a ladder stand. On two separate shop visits, the NTSB observed the box in the same location. Parts storage methods varied between the work areas. Some areas, however, were neat and orderly.

The NTSB also noted compartmentalization of the maintenance tasks within the airline's organization. Had any one of the various supervisors been more aware of the overall maintenance plan for the No. 1 pylon area, the NTSB surmised that the accident might not have occurred.

The NTSB believed that the FAA failed to apply their findings from previous human error studies. They should incorporate this knowledge into improved methods of identifying and correcting actual work site hazards (e.g., scaffolding, lights, housekeeping)

#### Has anything like this happened before?

Migrations of upper link fuse or diagonal brace fuse pins have been reported on five occasions by various airlines prior to this accident. One resulted in a similar accident four years earlier and Boeing issued a Service Letter recommending incorporation of the secondary retention devices. The other four were discovered during maintenance. A

seventh migration occurred after this case study accident. All of these incidents were attributed to the improper assembly of the components during maintenance.

NTSB Conclusions:

1. Maintenance and inspection personnel who worked on the accident aircraft were properly certificated.
2. Maintenance and inspection personnel who worked on the aircraft were not adequately trained and qualified to perform the required maintenance and inspections. Non-standard procedures were taught by OJT vice formalized training.
3. The mechanic who removed and failed to reinstall the No. 1 pylon aft diagonal brace primary retainer could not be identified.
4. The NDT inspector performed the test inspection improperly signed off subsequent steps on the CITEXT card. This could have led others to interpret that the maintenance actions on the No.1 engine had been completed when they had not.
5. The “OK to Close” inspection of the pylon area was hampered by inadequate lighting and perceived dangers of the scaffolding.
6. The CITEXT system used by this airline was inadequate because it lacked pertinent information from the maintenance manual, it did not follow the airline’s GEMM policy, and it did not contain specific instructions.
7. The mechanics and inspectors did not adequately understand the application of the CITEXT and red tag systems for critical maintenance items.
8. Supervisors and managers failed to ensure the mechanics and inspectors followed the approved maintenance manual procedures.
9. The work environment was inadequate and contributed to an error-producing situation for the workers.
10. The lack of adequate and organized storage of removed parts contributed to the failure to reinstall the fuse pin retainers.
11. FAA oversight of the maintenance facility failed to detect red tag procedural deviations.
12. FAA inspectors failed to apply the FAA-developed human factors elements, which allowed an inadequate work environment to exist.

NTSB Probable Cause: Maintenance and inspection personnel who worked on the airplane were not adequately trained and qualified to perform the required maintenance and inspection functions.

NTSB Contributing Causes: The work environment for the heavy maintenance of the airplane was inadequate and contributed to an error-producing situation for the workers.

# HFACS-ME Framework

Error Categories of HFACS Framework				
First Order	Second Order	Third Order		
Management Conditions	Organizational	- Inadequate Processes - Inadequate Resources	- Inadequate Documentation	- Inadequate Design
	Supervisory	- Inadequate Supervision - Supervisory Misconduct	- Inappropriate Operations	- Uncorrected Problem
Maintainer Conditions	Medical	- Mental State	- Physical State	- Limitation
	Crew Coordination	- Communication	- Assertiveness	- Adaptability/Flexibility
	Readiness	- Training/Preparation	- Certification/Qualification	- Infringement
Working Conditions	Environment	- Lighting/Light	- Weather/Exposure	- Environmental Hazards
	Equipment	- Damaged/Unserviced	- Unavailable/Inappropriate	- Dated/Uncertified
	Workspace	- Confining	- Obstructed	- Inaccessible
Maintainer Acts	Error	- Attention/Memory - Skill/Technique	- Judgment/Decision-Making	- Knowledge/Rule Based
	Violation	- Routine - Flagrant	- Infraction	- Exceptional

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